NUCLEAR TERMS

A GLOSSARY

IMATTER BARN BETATRON
EMSSTRAHLUNG COOLANT
GALITY CURIE CYCLOTRON
EUTERON FISSION FUSION
ISOMER ISOTOPE LATTICE
MESON MUON NEUTRINO
RITY PHOTON PROTON RAD
TIVITY ROENTGEN SCALER
M SYNCHROTRON TRACER
NSMUTATION TRITIUM VOID

U. S. ATOMIC ENERGY COMMISSION
Office of Information Services
A World of the Atom Series Booklet

The World of the Atom Series

Nuclear energy is playing a vital role in the life of every man, woman, and child in the United States today. In the years ahead it will affect increasingly all the peoples of the earth. It is essential that all Americans gain an understanding of this vital force if they are to discharge thoughtfully their responsibilities as citizens and if they are to realize fully the myriad benefits that nuclear energy offers them.

The United States Atomic Energy Commission provides this booklet to help you achieve such understanding.

FOREWORD

Terms defined in this glossary are among those commonly used in nuclear science and its applications. Some also are in common usage or apply in other specialized areas of science and technology. When this is the case, the definitions given are those which have special meaning in nuclear fields, unless otherwise indicated.

This glossary is intended for persons who are not specialists in the subject matter of atomic energy. Some definitions may for that reason fall short of technical precision or completeness. A reference list on page 66 includes other glossaries and detailed sources of information.

For cross-references, *italic* type is used. Definitions that employ or refer the reader to synonymous, parallel, similar, or related terms defined elsewhere in this glossary show such terms in *italics*. Example:

dry criticality — Reactor criticality achieved without a *coolant*. (Compare *wet criticality;* see *criticality*.)

Definitions expressed wholly or largely in terms defined elsewhere in this glossary also are set in italics. Example:

A-bomb — An *atomic bomb*.

In definitions that mention related general or collective subject areas, defined in this glossary, which are not necessarily synonymous to or parallel with the term being defined, but which may contribute understanding, these broad subject areas are printed in *CAPITAL ITALICS*. Example:

scintillation — A flash of light produced by a *phosphor* in an *IONIZING EVENT*.

The Appendix beginning on page 67 includes prefixes, units of measurement, constants, abbreviations, a Periodic Table and List of the Elements, tables of isotopes of some of the elements, principal fission products, and the four radioactive decay series.

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HOW THIS GLOSSARY WAS WRITTEN

This edition of "Nuclear Terms: A Brief Glossary" is an outgrowth of an earlier edition compiled by James D. Lyman of the Atomic Energy Commission Division of Public Information, who also served as its co-editor. Mr. Lyman years earlier had started a card file of definitions of nuclear terms to assist him in his work of answering inquiries from newsmen. The file grew to impressive proportions and proved so useful that others asked for copies.

The card file, somewhat enlarged, carefully edited, revised and reviewed by authorities both within and outside the Atomic Energy Commission, appeared in April 1964, as the first edition of this booklet. It proved to be one of the most popular of the "Understanding the Atom" series. More than 118,000 copies were distributed.

Numerous suggestions were made that the list of terms be enlarged. This has now been done. Mr. Lyman's original list contained 385 terms. The present volume contains 640. Moreover, the complete list has been reviewed anew by those who contributed to the first edition as well as by additional specialists.

Principal reviewers and contributors from outside the AEC were William R. Corliss, nuclear engineer, consultant and writer; Dr. John F. Hogerton, nuclear consultant and author of *The Atomic Energy Deskbook;* Dr. Samuel Glasstone, author of *Sourcebook on Atomic Energy* and many other technical volumes; and Dr. Charles W. Shilling, editor and principal contributor to *The Atomic Energy Encyclopedia in the Life Sciences.*

Many members of the AEC staff also contributed extensively to this edition, particularly Dr. Walter D. Claus, formerly with the Division of Biology and Medicine, and Dr. Benjamin S. Loeb, Division of Technical Information. Dr. John H. Pomeroy formerly with the AEC Division of Research was the technical editor. Harold F. Osborne formerly with the Division of Technical Information was editorial supervisor.

The complete list of terms in the first edition was edited and revised as necessary. In addition, by increased cross-referencing (see Foreword), similar and related terms were linked to provide greater utility and increase understanding.

NUCLEAR TERMS
A GLOSSARY
Second Edition

A

A Symbol for *mass number.*

A-bomb An *atomic bomb.*

absorbed dose When *IONIZING RADIATION* passes through *MATTER,* some of its energy is imparted to the matter. The amount absorbed per unit mass of irradiated material is called the absorbed dose, and is measured in *rems* and *rads.* (See *threshold dose.*)

absorber Any material that absorbs or diminishes the intensity of ionizing *RADIATION.* Neutron absorbers, like boron, hafnium, and cadmium, are used in control rods for reactors. Concrete and steel absorb gamma rays and neutrons in reactor shields. A thin sheet of paper or metal will absorb or attenuate alpha particles and all except the most energetic beta particles. (Compare *moderator;* see *poison.*)

absorption The process by which the number of *particles* or *photons* entering a body of *MATTER* is reduced by interaction of the particles or radiation with the matter; similarly, the reduction of the energy of a particle while traversing a body of matter. This term is sometimes erroneously used for capture. (Compare *capture;* see *stopping power.*)

accelerator A device for increasing the velocity and energy of charged *ELEMENTARY PARTICLES,* for example, electrons or protons, through application of electrical and/or magnetic forces. Accelerators have made particles move at velocities approaching the speed of light. Types of accelerators include *betatrons, Cockcroft-Walton accelerators, cyclotrons, linear accelerators, synchrocyclotrons, synchrotrons,* and *Van de Graaff generators.*

actinide series The series of elements beginning with actinium, Element No. 89, and continuing through lawrencium, Element No. 103, which together occupy one position in the *Periodic Table*. The series includes uranium, Element No. 92, and all the man-made transuranic elements. The group is also referred to as the "Actinides". (Compare *lanthanide series, transuranic elements*.) (See Appendix.)

actinium series (sequence) The series of nuclides resulting from the radioactive decay of uranium-235. Many man-made nuclides decay into this sequence. The end product of this sequence in nature is lead-207. (See *decay, radioactive*; *radioactive series*.) (See Appendix.)

activation The process of making a material radioactive by bombardment with neutrons, protons, or other nuclear *particles*. Also called *radioactivation*. (See *activation analysis, induced radioactivity*.)

activation analysis A method for identifying and measuring chemical elements in a sample of material. The sample is first made radioactive by bombardment with neutrons, charged particles, or gamma rays. The newly formed radioactive atoms in the sample then give off characteristic nuclear *radiations* (such as gamma rays) that tell what kinds of atoms are present and how many. Activation analysis is usually more sensitive than chemical analysis. It is used in research, industry, archeology, and criminology.

activity *radioactivity*. (See *specific activity*.)

AEC The *U. S. Atomic Energy Commission*.

aftercooling The cooling of a reactor after it has been shut down.

afterheat The heat produced by the continuing decay of radioactive atoms in a reactor after fission has stopped. Most of the afterheat is due to the radioactive decay of *fission products*.

air sampling The collection and analysis of samples of air to measure its radioactivity or to detect the presence of radioactive substances. (See *fallout*.)

allobar A form of an element differing in isotopic composition, having a different average *atomic weight* from the usually occurring form. (See *isotope*.)

alpha particle [Symbol α (alpha)] A positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons bound together, hence is identical with the nucleus of a helium atom. It is the least penetrating of the three common types of *radiation* (alpha, beta, gamma) emitted by radioactive material, being stopped by a sheet of paper. It is not dangerous to plants, animals or man unless the alpha-emitting substance has entered the body. (See *decay, radioactive*.)

alpha ray A stream of alpha particles. Loosely, a synonym for *alpha particle*.

angstrom [Symbol Å or A] A unit of length, used in measuring electromagnetic radiation, equal to 10^{-8} centimeter. Named for A. J. Ångstrom, Swedish spectroscopist. (See Appendix.)

annihilation (See *antimatter*.)

antimatter (antiparticles) Matter in which the ordinary nuclear *particles* (neutrons, protons, electrons, etc.) are conceived of as being replaced by their corresponding antiparticles (antineutrons, antiprotons, positrons, etc.). An antihydrogen atom, for example, would consist of a negatively charged antiproton with an orbital positron. Normal matter and antimatter would mutually annihilate each other upon contact, being converted totally into energy. (Compare *matter*.)

atom A particle of matter indivisible by chemical means. It is the fundamental building block of the chemical elements. The elements, such as iron, lead, and sulfur, differ from each other because they contain different kinds of atoms. There are about six sextillion (6 followed by 21 zeros, or 6×10^{21}) atoms in an ordinary drop of water. According to present-day theory, an atom contains a dense inner core (the *nucleus*) and a much less dense outer domain consisting of *electrons* in motion around the nucleus. Atoms are electrically neutral. (Compare *element, ion, molecule;* see *matter*.)

atom smasher An *accelerator*.

atomic battery A *radioisotopic generator*.

atomic bomb A bomb whose energy comes from the *fission* of heavy elements, such as uranium or plutonium. (Compare *hydrogen bomb*.)

atomic clock A device that uses the extremely fast vibrations of molecules or atomic nuclei to measure time. These vibrations remain constant with time, consequently short intervals can be measured with much higher precision than by mechanical or electrical clocks. (Compare *radioactive dating.*)

atomic cloud The cloud of hot gases, smoke, dust, and other matter that is carried aloft after the explosion of a nuclear weapon in the air or near the surface. The cloud frequently has a mushroom shape. (See *fireball, radioactive cloud.*)

atomic energy *nuclear energy.*

Atomic Energy Commission [Abbreviation AEC] The independent civilian agency of the federal government with statutory responsibility for atomic energy matters. Also the body of five persons, appointed by the President, to direct the agency.

atomic mass (See *atomic weight, mass.*)

atomic mass unit [Symbol amu] One-twelfth the mass of a neutral atom of the most abundant isotope of carbon, ^{12}C. (See *atomic weight, mass number.*)

atomic number [Symbol Z] The number of protons in the *nucleus* of an atom, and also its positive charge. Each chemical element has its characteristic atomic number, and the atomic numbers of the known elements form a complete series from 1 (hydrogen) to 103 (lawrencium). (Compare *atomic weight, mass number;* see *element, isotope, Periodic Table.*)

atomic reactor A *nuclear reactor.*

atomic weapon An explosive weapon in which the energy is produced by nuclear *fission* or *fusion.* (Compare *device, nuclear.*)

atomic weight The mass of an atom relative to other atoms. The present-day basis of the scale of atomic weights is carbon; the commonest isotope of this element has arbitrarily been assigned an atomic weight of 12. The unit of the scale is $^1/_{12}$ the weight of the carbon-12 atom, or roughly the mass of one proton or one neutron. The atomic weight of any element is approximately equal to the total number of protons and neutrons in its *nucleus.* (Compare *atomic number;* see *atomic mass unit, Periodic Table.*)

autoradiograph A photographic record of *radiation* from radioactive material in an object, made by placing the object very close to a photographic film or emulsion. The process is called autoradiography. It is used, for instance, to locate radioactive atoms or *tracers* in metallic or biological samples. (Compare *radiography.*)

B

background *background radiation.*

background radiation The radiation in man's natural environment, including cosmic rays and radiation from the naturally radioactive elements, both outside and inside the bodies of men and animals. It is also called *natural radiation.* The term may also mean radiation that is unrelated to a specific experiment. (See *cosmic rays.*)

backscatter When *radiation* of any kind strikes matter (gas, liquid or solid), some of it may be reflected or scattered back in the general direction of the source. An understanding or exact measurement of the amount of backscatter is important when beta particles are being counted in an ionization chamber, in medical treatment with radiation, or in use of industrial radioisotopic thickness gauges. (See *gauging.*)

barn [Symbol b] A unit area used in expressing the cross sections of atoms, nuclei, electrons, and other particles. One barn is equal to 10^{-24} square centimeter. (See *cross section.*) (See Appendix.)

barricade shield A type of movable shield for protection from radiation. (See *shield.*)

barrier shield A wall or enclosure shielding the operator from an area where radioactive material is being used or processed by remote control equipment. (See *shield.*)

baryon One of a class of heavy *elementary particles* that includes *hyperons, neutrons* and *protons.* (Compare *lepton, meson.*)

beam A stream of particles or electromagnetic radiation, going in a single direction.

beam hole An opening through a reactor shield and, generally, through the reactor reflector, which permits a beam of radioactive particles or radiation to be used for experiments outside the reactor.

beta particle [Symbol β (beta)] An *elementary particle* emitted from a nucleus during radioactive decay, with a single electrical charge and a mass equal to $^1/_{1837}$ that of a proton. A negatively charged beta particle is identical to an *electron.* A positively charged beta particle is called a *positron.* Beta radiation may cause skin burns, and beta-emitters are harmful if they enter the body. Beta particles are easily stopped by a thin sheet of metal, however. (See *decay, radioactive.*)

betatron A doughnut-shaped accelerator in which electrons, traveling in an orbit of constant radius, are accelerated by a changing magnetic field. Energies as high as 340 Mev have been attained. (See *accelerator.*)

Bev Symbol for billion (or 10^9) electron volts. Also written as BeV. (See *electron volt.*) (See Appendix.)

binding energy The binding energy of a *nucleus* is the minimum energy required to dissociate it into its component neutrons and protons. Neutron or proton binding energies are those required to remove a neutron or a proton, respectively, from a nucleus. Electron binding energy is that required to remove an electron from an atom or a molecule. (Compare *fission, ionization.*)

biological dose The radiation dose absorbed in biological material. Measured in *rems.* (See *absorbed dose.*)

biological half-life The time required for a biological system, such as a man or an animal, to eliminate, by natural processes, half the amount of a substance (such as a radioactive material) that has entered it. (Compare *half-life;* see *half-life, effective.*)

biological shield A mass of absorbing material placed around a reactor or radioactive source to reduce the radiation to a level that is safe for human beings. (See *absorber, shield, thermal shield.*)

blanket A layer of fertile material, such as uranium-238 or thorium-232, placed around the fissionable material in a reactor. (See *fertile material, seed core.*)

blast wave A pulse of air, propagated from an explosion, in which the pressure increases sharply at the front of a moving air mass, accompanied by strong, transient winds. (See *shock wave.*)

body burden The amount of radioactive material present in the body of a man or an animal. (See *background radiation, whole body counter.*)

boiling water reactor A reactor in which water, used as both coolant and moderator, is allowed to boil in the core. The resulting steam can be used directly to drive a turbine. (Compare *water boiler.*)

bone seeker A *radioisotope* that tends to accumulate in the bones when it is introduced into the body. An example is strontium-90, which behaves chemically like calcium.

brachytherapy Radiation treatment using a solid or enclosed radioisotopic source on the surface of the body or at a short distance from the area to be treated. (Compare *interstitial implants, teletherapy;* see *radiation therapy.*)

breeder reactor A reactor that produces fissionable fuel as well as consuming it, especially one that creates more than it consumes. The new *fissionable material* is created by capture in fertile materials of neutrons from fission. The process by which this occurs is known as *breeding.* (Compare *converter reactor;* see *fertile material.*)

breeding (See *breeder reactor.*)

breeding gain (See *breeding ratio.*)

breeding ratio The ratio of the number of fissionable atoms produced in a breeder reactor to the number of fissionable atoms consumed in the reactor. *Breeding gain* is the breeding ratio minus one. (Compare *conversion ratio.*)

bremsstrahlung *Electromagnetic radiation* emitted (as *photons*) when a fast-moving charged particle (usually an electron) loses energy upon being accelerated and deflected by the electric field surrounding a positively charged atomic nucleus. X rays produced in ordinary X-ray machines are bremsstrahlung. (In German, the term means "braking radiation".) (See *X ray.*)

bubble chamber A device used for detection and study of *elementary particles* and nuclear reactions. Charged particles from an *accelerator* are introduced into a superheated liquid, each forming a trail of bubbles along its path. The trails are photographed, and by studying the photograph scientists can identify the particles and analyze the nuclear events in which they originate. (Compare *cloud chamber, spark chamber.*)

burnable poison A neutron absorber (or poison), such as boron, which, when purposely incorporated in the fuel or fuel cladding of a *nuclear reactor*, gradually "burns up" (is changed into nonabsorbing material) under neutron irradiation. This process compensates for the loss of reactivity that occurs as fuel is consumed and fission-product poisons accumulate, and keeps the overall characteristics of the reactor nearly constant during its use. (See *poison, reactivity.*)

burner reactor A *converter reactor.*

burnup A measure of reactor *fuel* consumption. It can be expressed as (a) the percentage of fuel atoms that have undergone *fission*, or (b) the amount of energy produced per unit weight of fuel in the reactor.

by-product material Any radioactive material (except source material or fissionable material) obtained during the production or use of source material or fissionable material. It includes *fission products* and many other *radioisotopes* produced in nuclear reactors. (Compare *fissionable material, source material.*)

C

capacity factor *plant factor.*

capture A process in which an atomic or nuclear system acquires an additional particle; for example, the capture of electrons by positive ions, or capture of electrons or neutrons by nuclei. (See *absorption, K-capture, radiative capture.*)

carrier A stable *isotope*, or a normal element, to which radioactive atoms of the same element can be added to obtain a quantity of radioactive mixture sufficient for handling, or to produce a radioactive mixture that will undergo the same chemical or biological reaction as the stable isotope. A substance in weighable amount which, when associated with a trace of another substance, will carry the trace through a chemical, physical or biological process. (See *radioactive tracer; tracer, isotopic.*)

cascade A connected arrangement of units of equipment for separation of isotopes. A single device or process usually can produce only a small amount of isotopic separation, but if a number of these are connected together the effect can be multiplied and a significant amount of separation achieved. An example is a cascade of barriers for the gaseous diffusion process. (See *gaseous diffusion, isotope separation.*)

cathode rays A stream of *electrons* emitted by the cathode, or negative electrode, of a gas-discharge tube or by a hot filament in a vacuum tube, such as a television tube.

cave A *hot cell.*

Čerenkov radiation Light emitted when charged particles pass through a transparent material at a velocity greater than that of light in that material. It can be seen, for example, as a blue glow in the water around the fuel elements of pool reactors. P. A. Čerenkov was the Russian scientist who first explained the origin of this light. (See *radiation.*)

chain reaction A reaction that stimulates its own repetition. In a fission chain reaction a fissionable *nucleus* absorbs a neutron and fissions, releasing additional neutrons. These in turn can be absorbed by other fissionable nuclei, releasing still more neutrons. A fission chain reaction is self-sustaining when the number of neutrons released in a given time equals or exceeds the number of neutrons lost by absorption in non-fissioning material or by escape from the system. (See *criticality, fission.*)

charged particle An *ion;* an *elementary particle* that carries a positive or negative electric charge. (See *plasma.*)

chemical dosimeter A *detector* for indirect measurement of radiation by indicating the extent to which the radiation causes a definite chemical change to take place. (Compare *film badge, ionization chamber;* see *dosimeter.*)

chemical shim Chemicals, such as boric acid, which are placed in a *reactor* coolant to control the reactor by absorbing neutrons. (Compare *burnable poison, shim rod;* see *absorber.*)

chopper A rotating shutter for interrupting an otherwise continuous stream of particles. Choppers can release short bursts of neutrons with known energies, used to measure nuclear cross sections. (See *beam, cross section.*)

cladding The outer jacket of nuclear *fuel elements.* It prevents corrosion of the fuel and the release of fission products into the coolant. Aluminum or its alloys, stainless steel and zirconium alloys are common cladding materials.

clean bomb A nuclear bomb that produces relatively little radioactive *fallout.* A *fusion* bomb. (Compare *dirty bomb.*)

closed-cycle reactor system A reactor design in which the primary heat of fission is transferred outside the reactor core to do useful work by means of a *coolant* circulating in a completely closed system that includes a *heat exchanger.* (Compare *direct-cycle reactor system, indirect-cycle reactor system, open-cycle reactor system.*)

cloud chamber A device in which the tracks of charged atomic *particles,* such as *cosmic rays* or *accelerator* beams, are displayed. It consists of a glass-walled chamber filled with a supersaturated vapor, such as wet air. When charged particles pass through the chamber, they trigger a process of condensation, and so produce a track of tiny liquid droplets, much like the vapor trail of a jet plane. This track permits scientists to study the particles' motions and interactions. (Compare *bubble chamber, spark chamber.*)

cobalt bomb If a nuclear weapon were encased in cobalt, large amounts of radioactive cobalt-60 could be produced when it was detonated. Such a weapon (only theoretical today) could add to the explosive force of the bomb the danger of the highly penetrating and long-lasting gamma radiation emitted by cobalt-60.

Cockcroft-Walton accelerator A device for accelerating *charged particles* by the action of a high direct-current voltage on a stream of gas ions in a straight insulated tube; the voltage is generated by a voltage multiplier system consisting essentially of a number of condenser pairs connected through switching devices (vacuum tubes). The particles (which are nuclei of an ionized gas, such as protons from hydrogen) gain energies of up to several million electron volts from the single acceleration so produced. Named for the British physicists, J. D. Cockcroft and E. T. S. Walton, who developed this machine in the 1930s. (See *accelerator.*)

coffin A heavily shielded shipping cask for spent (used) *fuel elements.* Some coffins weigh as much as 75 tons.

coincidence counting A method for detecting or identifying radioactive materials and for calibrating their disintegration rates by counting two or more characteristic *radiation* events (such as gamma ray emissions) which occur together or in a specific time relationship to each other. This method is important in activation analysis, medical scanning, cosmic ray studies and low-level measurements. (See *counter, low-level counting.*)

collimator A device for focusing or confining a *beam* of particles or radiation, such as X rays.

collision A close approach of two or more *particles, photons,* atoms or nuclei, during which such quantities as energy, momentum and charge may be exchanged. (See *Compton effect, excited state, pair production, scattering.*)

Compton effect Elastic scattering of *photons* (X rays or gamma rays) by *electrons.* In each such process the electron gains energy and recoils, and the photon loses energy. This is one of three ways photons lose energy upon interacting with matter, and is the usual method with photons of intermediate energy and materials of low atomic number. It is named for A. H. Compton, American physicist, who discovered it in 1923. (See *collision, pair production, scattering.*)

containment The provision of a gastight shell or other enclosure around a *reactor* to confine fission products that otherwise might be released to the atmosphere in the event of an accident.

containment vessel A gas tight shell or other enclosure around a reactor. (Compare *pressure vessel;* see *containment.*)

contamination (See *radioactive contamination.*)

control rod A rod, plate, or tube containing a material that readily absorbs *neutrons* (hafnium, boron, etc.), used to control the power of a *nuclear reactor.* By absorbing neutrons, a control rod prevents the neutrons from causing further *fission.* (See *absorber, regulating rod, safety rod,* and *shim rod,* which are types of control rods.)

controlled fusion experiment (See *controlled thermonuclear reaction.*)

controlled thermonuclear reaction Controlled *fusion*, that is, fusion produced under research conditions, or for production of useful power. (See *Sherwood*.)

conversion (See *converter reactor.*)

conversion ratio The ratio of the number of atoms of new *fissionable material* produced in a *converter reactor* to the original number of atoms of fissionable fuel consumed. (Compare *breeding ratio.*)

converter reactor A reactor that produces some *fissionable material*, but less than it consumes. In some usages, a reactor that produces a fissionable material different from the fuel burned, regardless of the ratio. In both usages the process is known as *conversion.* (Compare *breeder reactor.*)

coolant A substance circulated through a *nuclear reactor* to remove or transfer heat. Common coolants are water, air, carbon dioxide, liquid sodium and sodium-potassium alloy (NaK).

core The central portion of a *nuclear reactor* containing the *fuel elements* and usually the *moderator*, but not the *reflector.*

cosmic rays Radiation of many sorts but mostly atomic *nuclei (protons)* with very high energies, originating outside the earth's atmosphere. Cosmic radiation is part of the natural *background radiation.* Some cosmic rays are more energetic than any man-made forms of radiation. (See *neutrino.*)

counter A general designation applied to *radiation detection instruments* or *survey meters* that detect and measure radiation in terms of individual ionizations, displaying them either as the accumulated total or their rate of occurrence. (See *Geiger-Müller counter*, *scaler.*)

critical Capable of sustaining a *chain reaction.* (See *criticality.*)

critical assembly An assembly of sufficient fissionable material and moderator to sustain a fission *chain reaction* at a very low power level. This permits study of the behavior of the components of the assembly for various fissionable materials in different geometrical arrangements. (Compare *nuclear reactor.*)

critical experiment An experiment to verify or supplement calculations of the critical size and other physical data affecting a *reactor* design. The power is kept so low that a system for removing heat is not required.

critical facility A facility where *critical experiments* are conducted.

critical mass The smallest mass of *fissionable material* that will support a self-sustaining *chain reaction* under stated conditions.

criticality The state of a nuclear reactor when it is sustaining a *chain reaction.* (See *dry criticality, multiplication factor, prompt criticality, reactivity, wet criticality.*)

cross section [Symbol σ (sigma)] A measure of the probability that a *NUCLEAR REACTION* will occur. Usually measured in *barns*, it is the apparent (or effective) area presented by a *target* nucleus (or particle) to an oncoming particle or other nuclear radiation, such as a photon of gamma radiation.

curie [Symbol c] The basic unit to describe the intensity of *radioactivity* in a sample of material. The curie is equal to 37 billion disintegrations per second, which is approximately the rate of decay of 1 gram of *radium.* A curie is also a quantity of any nuclide having 1 curie of radioactivity. Named for Marie and Pierre Curie, who discovered radium in 1898. (Compare *rem, roentgen.*) (See Appendix.)

cutie pie A common radiation *survey meter* used to determine exposure levels or to locate possible radiation hazards. (See *monitor.*)

cyclotron A particle *accelerator* in which charged particles receive repeated synchronized accelerations by electrical fields as the particles spiral outward from their source. The particles are kept in the spiral by a powerful magnetic field. (Compare *synchrocyclotron.*)

D

daughter A nuclide formed by the radioactive decay of another nuclide, which in this context is called the *parent.* (See *radioactive series.*) (See Appendix.)

decay chain A *radioactive series.*

decay heat The heat produced by the decay of radioactive nuclides. (See *afterheat; decay, radioactive; SNAP.*)

decay, radioactive The spontaneous transformation of one nuclide into a different nuclide or into a different energy state of the same nuclide. The process results in a decrease, with time, of the number of the original radioactive atoms in a sample. It involves the emission from the *nucleus* of *alpha particles, beta particles* (or electrons), or *gamma rays;* or the nuclear capture or ejection of orbital electrons; or fission. Also called *radioactive disintegration.* (See *half-life, nuclear reaction, radioactive series.*) (See Appendix.)

decontamination The removal of radioactive contaminants from surfaces or equipment, as by cleaning and washing with chemicals. (See *radioactive contamination.*)

delayed neutrons Neutrons emitted by radioactive *fission products* in a *reactor* over a period of seconds or minutes after a fission takes place. Fewer than 1% of the neutrons are delayed, the majority being *prompt neutrons.* Delayed neutrons are important considerations in reactor design and control. (See *dollar.*)

depleted fuel (See *depleted uranium, spent fuel.*)

depleted uranium Uranium having a smaller percentage of uranium-235 than the 0.7% found in natural uranium. It is obtained from the spent (used) fuel elements or as by-product *tails,* or residues, of uranium *isotope separation.* (Compare *natural uranium, spent fuel.*)

detector Material or a device that is sensitive to radiation and can produce a response signal suitable for measurement or analysis. A *radiation detection instrument.*

deuterium [Symbol ^{2}H or D] An *isotope* of hydrogen whose nucleus contains one neutron and one proton and is therefore about twice as heavy as the nucleus of normal hydrogen, which is only a single proton. Deuterium is often referred to as *heavy hydrogen;* it occurs in nature as 1 atom to 6500 atoms of normal hydrogen. It is nonradioactive. (See *heavy water, hydrogen.*)

deuteron The nucleus of *deuterium.* It contains one proton and one neutron.

device, nuclear A *nuclear explosive* used for peaceful purposes, tests or experiments. The term is used to distinguish these explosives from nuclear weapons, which are packaged units ready for transportation or use by military forces. (Compare *nuclear weapons.*)

diffusion plant (See *gaseous diffusion.*)

direct-cycle reactor system A nuclear power plant system in which the *coolant* or heat transfer fluid circulates first through the reactor and then directly to a turbine. (Compare *indirect-cycle reactor system.*)

dirty bomb A *fission bomb* or any other weapon which would distribute relatively large amounts of radioactivity upon explosion, as distinguished from a fusion weapon. (Compare *clean bomb.*)

discriminator An electronic circuit which selects signal pulses according to their *pulse height* or voltage. It is used to delete extraneous radiation counts or *background radiation,* or as the basis for energy spectrum analysis.

disintegration, radioactive Equivalent to *radioactive decay.*

distribution factor A term used to express the modification of the effect of radiation in a biological system attributable to the nonuniform distribution of an internally deposited isotope, such as radium's being concentrated in bones. (See *absorbed dose, dose equivalent, quality factor, relative biological effectiveness.*)

dollar A unit of reactivity. One dollar is the maximum amount of reactivity in a reactor due to *delayed neutrons* alone. (See *reactivity.*) (See Appendix.)

Doppler effect The shift with temperature of the interaction rate between neutrons and reactor materials, such as fuel rods, structural materials, and fertile materials. The shift can appreciably affect the neutron density and hence the *reactivity* of reactors. (See *neutron density.*)

dose (See *absorbed dose, biological dose, maximum permissible dose, threshold dose.*)

dose equivalent A term used to express the amount of effective radiation when modifying factors have been considered. The product of *absorbed dose* multiplied by a *quality factor* multiplied by a *distribution factor.* It is expressed numerically in *rems.*

dose rate The radiation dose delivered per unit time and measured, for instance, in rems per hour. (See *absorbed dose, rem.*)

dosimeter A device that measures radiation dose, such as a *film badge* or *ionization chamber.* (See *radiation dosimetry.*)

dosimetry (See *radiation dosimetry.*)

doubling time The time required for a breeder reactor to produce as much fissionable material as the amount usually contained in its core plus the amount tied up in its fuel cycle (fabrication, reprocessing, etc.). It is estimated as 10 to 20 years in typical reactors. (See *breeder reactor, fuel cycle.*)

dry criticality Reactor criticality achieved without a *coolant.* (Compare *wet criticality;* see *criticality.*)

dual-cycle reactor system A reactor-turbine system in which part of the steam fed to the turbine is generated directly in the reactor and part in a separate heat exchanger. A combination of *direct-cycle* and *indirect-cycle reactor systems.*

dual-purpose reactor A reactor designed to achieve two purposes, for example, to produce both electricity and new fissionable material.

E

effective half-life (See *half-life, effective.*)

effective multiplication factor (or constant) (See *multiplication factor.*)

Einstein equation (See *mass-energy equation.*)

elastic scattering (See *Compton effect, scattering.*)

electromagnetic radiation Radiation consisting of associated and interacting electric and magnetic waves that travel at the speed of light. Examples: light, radio waves, *gamma rays, X rays.* All can be transmitted through a vacuum. (Compare *ionizing radiation;* see *quantum.*)

electron [Symbol e^-] An *elementary particle* with a unit negative electrical charge and a mass $^1/_{1837}$ that of the *proton.* Electrons surround the positively charged *NUCLEUS* and determine the chemical properties of the *atom.* Positive electrons, or *positrons,* also exist. (Compare *antimatter;* see *pair production, shell.*)

electron capture [Abbreviation EC] A mode of *radioactive decay* of a nuclide in which an orbital electron is captured by and merges with the nucleus, thus forming a new nuclide with the *mass number* unchanged but the *atomic number* decreased by 1. (See *K-capture.*)

electron volt [Abbreviation ev or eV] The amount of *kinetic energy* gained by an electron when it is accelerated through an electric potential difference of 1 volt. It is equivalent to 1.603×10^{-12} erg. It is a unit of energy, or work, not of voltage. (See *Bev, Mev.*) (See Appendix.)

element One of the 103 known chemical substances that cannot be divided into simpler substances by chemical means. A substance whose atoms all have the same *atomic number.* Examples: hydrogen, lead, uranium. (Not to be confused with *fuel element.*) (See *atom, matter, nuclide.*) (See Appendix.)

elementary particles The simplest particles of *matter* and *radiation.* Most are short-lived and do not exist under normal conditions (exceptions are electrons, neutrons, protons and *neutrinos*). Originally this term was applied to any particle that could not be subdivided, or to constituents of atoms; now it is applied to *nucleons* (*protons* and *neutrons*), *electrons, mesons, muons, baryons, strange particles,* and the *anti-particles* of each of these, and to *photons,* but not to *alpha particles* or *deuterons.* Also called *fundamental particles.*

end product (See *radioactive series.*)

energy The capability of doing work. (See *kinetic energy, nuclear energy.*)

enriched material Material in which the percentage of a given *isotope* present in a material has been artificially increased, so that it is higher than the percentage of that isotope naturally found in the material. Enriched *uranium* contains more of the fissionable isotope uranium-235 than the naturally occurring percentage (0.7%). (See *isotopic enrichment.*)

enrichment *isotopic enrichment.*

epithermal neutron An *intermediate neutron.*

epithermal reactor An *intermediate reactor.*

equivalent ton (See *TNT equivalent.*)

excess reactivity More reactivity than that needed to achieve criticality Excess reactivity is built into a reactor (by using extra fuel) in order to compensate for fuel *burnup* and the accumulation of fission-product *poisons* during operation. (See *criticality, reactivity.*)

excited state The state of a molecule, atom, electron or nucleus when it possesses more than its normal *energy.* Excess nuclear energy is often released as a gamma ray. Excess molecular energy may appear as fluorescence or heat. (Compare *ground state.*)

exclusion area An area immediately surrounding a nuclear reactor where human habitation is prohibited to assure safety in the event of accident. (See *low population zone.*)

excursion A sudden, very rapid rise in the power level of a reactor caused by *supercriticality.* Excursions are usually quickly suppressed by the negative temperature coefficient of the reactor and/or by automatic control rods. (See *safety rod, scram, temperature coefficient of reactivity.*)

experimental reactor A reactor to test the design of new reactors. (Compare *research reactor, test reactor.*)

F

fallout Air-borne particles containing radioactive material which fall to the ground following a nuclear explosion. "Local fallout" from nuclear detonations falls to the earth's surface within 24 hours after the detonation. "Tropospheric fallout" consists of material injected into the troposphere but not into the higher altitudes of the stratosphere. It does not fall out locally, but usually is deposited in relatively narrow bands around the earth at about the latitude of injection. "Stratospheric fallout" or "worldwide fallout" is that which is injected into the stratosphere and which then falls out relatively slowly over much of the earth's surface. (Compare *background radiation.*)

fast breeder reactor A reactor that operates with fast neutrons and produces more *fissionable material* than it consumes. (See *breeder reactor, fast neutron, fast reactor.*)

fast neutron A neutron with energy greater than approximately 100,000 electron volts. (Compare *intermediate neutron, prompt neutron, thermal neutron.*)

fast reactor A reactor in which the fission *chain reaction* is sustained primarily by *fast neutrons* rather than by thermal or intermediate neutrons. Fast reactors contain little or no *moderator* to slow down the neutrons from the speeds at which they are ejected from fissioning nuclei. (Compare *intermediate reactor, thermal reactor.*)

feed materials Refined uranium or thorium metal or their pure compounds in a form suitable for use in nuclear reactor fuel elements or as feed for uranium enrichment processes. (See *enriched material.*)

fertile material A material, not itself fissionable by thermal neutrons, which can be converted into a fissile material by irradiation in a reactor. There are two basic fertile materials, uranium-238 and thorium-232. When these fertile materials capture neutrons, they are partially converted into fissile plutonium-239 and uranium-233, respectively. (Compare *fissile material.*)

film badge A light-tight package of photographic film worn like a badge by workers in nuclear industry or research, used to measure possible exposure to *IONIZING RADIATION.* The *absorbed dose* can be calculated by the degree of film darkening caused by the irradiation. (Compare *ionization chamber;* see *dosimeter.*)

fireball The luminous ball of hot gases that forms a few millionths of a second after a nuclear explosion. (See *atomic cloud.*)

fissile material While sometimes used as a synonym for fissionable material, this term has also acquired a more restricted meaning, namely, any material fissionable by neutrons of all energies, including (and especially) thermal (slow) neutrons as well as fast neutrons; for example, uranium-235 and plutonium-239. (See *fissionable material.*)

fission The splitting of a heavy *nucleus* into two approximately equal parts (which are nuclei of lighter elements), accompanied by the release of a relatively large amount of energy and generally one or more neutrons. Fission can occur spontaneously, but usually is caused by nuclear absorption of gamma rays, neutrons or other particles. (Compare *fusion;* see *chain reaction, nuclear reaction.*)

fission fragments The two nuclei which are formed by the fission of a nucleus. Also referred to as *primary fission products*. They are of medium atomic weight, and are radioactive. (See *fission products.*)

fission-product poisoning The absorption or capture of neutrons by fission products in a reactor, decreasing its *reactivity.* (See *poison.*)

fission products The nuclei (*fission fragments*) formed by the fission of heavy elements, plus the nuclides formed by the fission fragments' radioactive decay. (Compare *fission fragments;* see *decay, radioactive.*) (See Appendix.)

fission weapon An *atomic bomb.*

fission yield The amount of energy released by fission in a thermonuclear (fusion) explosion as distinct from that released by fusion. Also the amount (percentage) of a given nuclide produced by fission. (Compare *yield;* see *thermonuclear reaction, TNT equivalent.*)

fissionable material Commonly used as a synonym for fissile material. The meaning of this term also has been extended to include material that can be fissioned by *fast neutrons* only, such as uranium-238. Used in *reactor* operations to mean *fuel.* (Compare *fertile material, fissile material.*)

flash burn A skin burn due to a flash of *thermal radiation.* It can be distinguished from a flame burn by the fact it occurs on unshielded parts of the body that are in a direct line with the origin of the thermal radiation. (See *ionizing radiation, thermal burn.*)

fluid fuel reactor A type of reactor (for example, a *fused-salt reactor*) whose fuel is in fluid form.

fluidized bed reactor A reactor design in which the *fuel* ranges in size from small particles to pellets. Although the fuel particles are solid, their entire mass behaves like a fluid because a stream of liquid or gas *coolant* keeps them moving.

fluorescence Many substances can absorb energy (as from X rays, ultraviolet light, or radioactive particles), and immediately emit this energy as an electromagnetic *photon,* often of visible light. This emission is fluorescence. The emitting substances are said to be fluorescent. (Compare *luminescence, scintillation;* see *excited state.*)

fluoroscope An instrument with a fluorescent screen suitably mounted with respect to an X-ray tube, used for immediate indirect viewing of internal organs of the body, internal structures in apparatus or masses of metals, by means of X rays. A fluorescent image, really a kind of X-ray shadow picture, is produced. (See *X ray.*)

flux (neutron) A measure of the intensity of neutron radiation. It is the number of neutrons passing through 1 square centimeter of a given *target* in 1 second. Expressed as nv, where n = the number of neutrons per cubic centimeter and v = their velocity in centimeters per second. (See *integrated neutron flux, intensity, neutron density.*)

food chain The pathways by which any material (such as radioactive material from *fallout*) passes from the first absorbing organism through plants and animals to man.

fuel Fissionable material used or usable to produce energy in a *reactor.* Also applied to a mixture, such as *natural uranium,* in which only part of the atoms are readily fissionable, if the mixture can be made to sustain a chain reaction. (See *fissionable material.*)

fuel cycle The series of steps involved in supplying fuel for nuclear power reactors. It includes mining, refining, the original fabrication of fuel elements, their use in a reactor, chemical processing to recover the fissionable material remaining in the spent fuel, reenrichment of the fuel material, and refabrication into new fuel elements.

fuel element A rod, tube, plate, or other mechanical shape or form into which nuclear fuel is fabricated for use in a reactor. (Not to be confused with *element.*) (See *nuclear reactor.*)

fuel reprocessing The processing of reactor fuel to recover the unused fissionable material. (See *recycling, spent fuel.*)

fundamental particles *elementary particles.*

fused-salt reactor A type of reactor that uses molten salts of uranium for both *fuel* and *coolant.*

fusion The formation of a heavier *nucleus* from two lighter ones (such as hydrogen isotopes), with the attendant release of energy (as in a *hydrogen bomb*). (Compare *fission;* see *nuclear reaction, Sherwood, thermonuclear reaction.*)

fusion weapon An atomic weapon using the energy of nuclear *fusion*, such as a *hydrogen bomb.*

G

gaging *gauging.*

gamma rays [Symbol γ (gamma)] High-energy, short-wavelength *electromagnetic radiation.* Gamma radiation frequently accompanies alpha and beta emissions and always accompanies *fission.* Gamma rays are very penetrating and are best stopped or shielded against by dense materials, such as lead or depleted uranium. Gamma rays are essentially similar to X rays, but are usually more energetic, and are nuclear in origin. (Compare *X ray;* see *decay radioactive, excited state, photon.*)

gas centrifuge process A method of isotopic separation in which heavy gaseous atoms or molecules are separated from light ones by centrifugal force. (See *isotope separation.*)

gas-cooled reactor A nuclear reactor in which a gas is the coolant.

gaseous diffusion (plant) A method of isotopic separation based on the fact that gas atoms or molecules with different masses will diffuse through a porous barrier (or membrane) at different rates. The method is used by the AEC to separate uranium-235 from uranium-238; it requires large gaseous-diffusion plants and enormous amounts of electric power. (See *cascade, isotope separation, uranium hexafluoride.*)

gauging The measurement of the thickness, density or quantity of material by the amount of *radiation* it absorbs. This is the most common use of radioactive isotopes in industry. Also spelled *gaging.*

Geiger-Müller counter (Geiger-Müller tube) A radiation detection and measuring instrument. It consists of a gas-filled (Geiger-Müller) tube containing electrodes, between which there is an electrical voltage but no current flowing. When *ionizing radiation* passes through the tube, a short, intense *pulse* of current passes from the negative electrode to the positive electrode and is measured or counted. The number of pulses per second measures the *intensity* of radiation. It is also often known as *Geiger counter*; it was named for Hans Geiger and W. Müller who invented it in the 1920s. (See *counter.*)

generation time The mean time for the neutrons produced by one fission to produce fissions again in a chain reaction. (See *chain reaction.*)

genetic effects of radiation Radiation effects that can be transferred from parent to offspring. Any radiation-caused changes in the genetic material of sex cells. (Compare *radiomutation, somatic effects of radiation.*)

geometry The spatial configuration, pattern or relationship of components in an experiment or apparatus. In reactor technology, the term refers to the shape and size of fuel elements, moderator and reflector and their location with respect to each other. In nuclear physics, it refers to the arrangement of source and detecting equipment. In counting and scanning, the term commonly indicates the percentage of the radiation leaving a sample which reaches the sensitive volume of a counter. (See *lattice.*)

glory hole A *beam hole.*

glove box A sealed box in which workers, using gloves attached to and passing through openings in the box, can handle radioactive materials safely from the outside.

graphite A very pure form of carbon used as a moderator in nuclear reactors.

green salt *uranium tetrafluoride.*

ground state The state of a nucleus, atom or molecule at its lowest (normal) *energy* level. (Compare *excited state.*)

ground zero The point on the surface of land or water vertically below or above the center of a burst of a nuclear explosion. For a burst over or under water, the term *surface zero* is preferable.

H

H-bomb A *hydrogen bomb.*

half-life The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billions of years. (See *decay, radioactive.*) (See Appendix.)

half-life, biological (See *biological half-life.*)

half-life, effective The time required for a radionuclide contained in a biological system, such as a man or an animal, to reduce its activity by half as a combined result of radioactive decay and biological elimination. (Compare *biological half-life;* see *half-life.*)

half-thickness The thickness of any given *absorber* that will reduce the intensity of a beam of radiation to one-half its initial value.

half-time (See *residence time.*)

half-value layer The thickness of any particular material necessary to reduce the *dose rate* of an X-ray beam to one-half its original value.

hand and foot counter A monitoring device arranged to give a rapid radiation survey of hands and feet of persons working with radioactive materials, to detect radioactive contamination. (See *counter, monitor, personnel monitoring, radioactive contamination.*)

health physics The science concerned with recognition, evaluation, and control of health hazards from *ionizing radiation.*

heat exchanger Any device that transfers heat from one fluid (liquid or gas) to another or to the environment.

heat sink Anything that absorbs heat; usually part of the environment, such as the air, a river, or outer space.

heavy hydrogen *deuterium.*

heavy water [Symbol D_2O] Water containing significantly more than the natural proportion (one in 6500) of heavy hydrogen (*deuterium*) atoms to ordinary *hydrogen* atoms. Heavy water is used as a moderator in some reactors because it slows down neutrons effectively and also has a low cross section for absorption of neutrons.

heavy-water-moderated reactor A reactor that uses *heavy water* as its moderator. Heavy water is an excellent moderator and thus permits the use of inexpensive natural (unenriched) uranium as a fuel.

heterogeneous reactor A reactor in which the fuel is separate from the moderator and is arranged in discrete bodies, such as *fuel elements.* Most reactors are heterogeneous. (Compare *homogeneous reactor.*)

homogeneous reactor A reactor in which the fuel is mixed with or dissolved in the moderator or coolant. Example: a fused-salt reactor. (Compare *heterogeneous reactor.*)

hood A protective device, usually providing special ventilation to carry away gases, in which dangerous chemical, biological, or radioactive materials can be safely handled.

hot Highly radioactive.

hot cell A heavily shielded enclosure in which radioactive materials can be handled by persons using remote *manipulators* and viewing the materials through shielded windows or periscopes. (See *shield.*)

hot laboratory A laboratory designed for the safe handling of radioactive materials, and usually containing one or more *hot cells.*

hot spot A surface area of higher-than-average *radioactivity.* Also a part of a *fuel element* surface that has become overheated.

hydrogen [Symbol H] The lightest element, No. 1 in the atomic series. It has two natural *isotopes* of atomic weights 1 and 2. The first is ordinary hydrogen, or light hydrogen; the second is *deuterium,* or heavy hydrogen. A third isotope, *tritium,* atomic weight 3, is a radioactive form produced in reactors by bombarding lithium-6 with neutrons. (See Appendix.)

hydrogen bomb A nuclear weapon that derives its energy largely from *fusion.* (See *thermonuclear reaction.*)

hyperon One of a class of short-lived *elementary particles* with a mass greater than that of a proton and less than that of a deuteron. All hyperons are unstable and yield a nucleon as a decay product. (See *baryon.*)

I

implosion weapon A weapon in which a quantity of fissionable material, less than a *critical mass* at ordinary pressure, has its volume suddenly reduced by compression (a step accomplished by using chemical explosives) so that it becomes supercritical, producing a nuclear explosion. (See *supercritical mass.*)

indirect-cycle reactor system A reactor system in which a *heat exchanger* transfers heat from the reactor *coolant* to a second fluid which then drives a turbine. (Compare *closed-cycle reactor system, direct-cycle reactor system.*)

induced radioactivity Radioactivity that is created when substances are bombarded with neutrons, as from a nuclear explosion or in a reactor, or with charged particles produced by accelerators. (See *activation.*)

inelastic scattering (See *scattering.*)

initial nuclear radiation Radiation emitted from the *fireball* of a nuclear explosive during the first minute (an arbitrary time interval) after detonation. (Compare *residual nuclear radiation.*)

in-pile A term used to designate experiments or equipment inside a reactor. (See *pile.*)

in-pile loop (See *loop.*)

integrated neutron flux Flux multiplied by time, usually expressed as nvt, when n = the number of neutrons per cubic centimeter, v = their velocity in centimeters per second, and t = time in seconds. (See *flux.*)

intensity The energy or the number of photons or particles of any *radiation* incident upon a unit area or flowing through a unit of solid material per unit of time. In connection with *radioactivity,* the number of atoms disintegrating per unit of time. (See *flux.*)

intermediate (epithermal) neutron A neutron having energy greater than that of a thermal neutron but less than that of a fast neutron. The range is generally considered to be between about 0.5 and 100,000 electron volts. (Compare *fast neutron, thermal neutron.*)

intermediate (epithermal) reactor A reactor in which the chain reaction is sustained mainly by *intermediate neutrons.* (Compare *fast reactor, thermal reactor.*)

interstitial implants Solid or encapsulated *radiation sources,* made in the form of seeds, wires or other shapes to be inserted directly into tissue that is to be irradiated. (See *brachytherapy.*)

ion An atom or molecule that has lost or gained one or more *electrons.* By this *ionization* it becomes electrically charged. Examples: an alpha particle, which is a helium atom minus two electrons; a proton, which is a hydrogen atom minus its electron. (Compare *atom, elementary particles, molecule.*)

ion engine An engine which provides thrust by expelling accelerated or high velocity ions. Ion engines using energy provided by nuclear reactors are proposed for space vehicles.

ion exchange A chemical process involving the reversible interchange of various ions between a solution and a solid material, usually a plastic or a resin. It is used to separate and purify chemicals, such as *fission products, rare earths,* etc., in solutions.

ion pair A closely associated positive ion and negative ion (usually an electron) having charges of the same magnitude and formed from a neutral atom or molecule by radiation. (Compare *pair production.*)

ionization The process of adding one or more *electrons* to, or removing one or more electrons from, atoms or molecules, thereby creating *ions.* High temperatures, electrical discharges, or nuclear radiations can cause ionization.

ionization chamber An instrument that detects and measures ionizing radiation by measuring the electrical current that flows when radiation ionizes gas in a chamber, making the gas a conductor of the electricity. (Compare *chemical dosimeter, film badge.*)

ionizing event Any occurrence in which an ion or group of ions is produced; for example, by passage of a *charged particle* through *matter.*

ionizing radiation Any radiation displacing electrons from atoms or molecules, thereby producing *ions.* Examples: alpha, beta, gamma radiation, short-wave ultraviolet light. Ionizing radiation may produce severe skin or tissue damage. (See *radiation, radiation burn, radiation illness.*)

irradiation Exposure to radiation, as in a nuclear reactor. (See *spent fuel.*)

isobar One of two or more nuclides having about the same *atomic mass* but different *atomic numbers,* hence different chemical properties. Example: $^{14}_{6}C$, $^{14}_{7}N$, and $^{14}_{8}O$ are isobars. (Compare *isotope.*)

isodose curves Curves or lines drawn to connect points where identical amounts of radiant energy reach a certain depth in tissue.

isointensity contours Imaginary lines on the surface of the ground or water, or lines drawn on a map, joining points in a radiation field which have the same radiation intensity at a given time.

isomer One of two or more nuclides with the same numbers of neutrons and protons in their nuclei, but with different energies; a nuclide in the *excited state* and a similar nuclide in the *ground state* are isomers. (Compare *isotope.*)

isotone One of several nuclides having the same number of neutrons but a different number of protons in their nuclei. Example: potassium-39 ($^{39}_{19}K_{20}$) and calcium-40 ($^{40}_{20}Ca_{20}$) are isotones. (Compare *isotope.*)

isotope One of two or more atoms with the same *atomic number* (the same chemical element) but with different *atomic weights.* An equivalent statement is that the nuclei of isotopes have the same number of protons but different numbers of neutrons. Thus, $^{12}_{6}C$, $^{13}_{6}C$, and $^{14}_{6}C$ are isotopes of the element carbon, the subscripts denoting their common *atomic numbers,* the superscripts denoting the differing *mass numbers,* or approximate atomic weights. Isotopes usually have very nearly the same chemical properties, but somewhat different physical properties. (Compare *isobar, isotone, nuclide;* see *radioisotope.*) (See Appendix.)

isotope farm A carbon-14 growth chamber, or greenhouse, arranged as a closed system in which plants can be grown in a carbon-14 dioxide ($^{14}CO_2$) atmosphere and thus become labeled with ^{14}C. Isotope farms also can be used with other labeled materials, such as heavy water (D_2O), phosphorus-35 (^{35}P), etc., to produce biochemically labeled compounds. (See *tracer, isotopic.*)

isotope separation The process of separating isotopes from one another, or changing their relative abundances, as by *gaseous diffusion* or electromagnetic separation. All systems are based on the mass differences of the isotopes. Isotope separation is a step in the *isotopic enrichment* process. (See *mass spectrometer.*)

isotopic enrichment A process by which the relative abundances of the isotopes of a given element are altered, thus producing a form of the element which has been enriched in one particular isotope. Example: enriching *natural uranium* in the uranium-235 isotope. (See *enriched material, gaseous diffusion.*)

K

K-capture The capture by an atomic *nucleus* of an orbital *electron* from the first (innermost) orbit or *shell,* or K-shell, surrounding the nucleus. (See *atom, capture, electron capture.*)

K-meson (See *kaon.*)

kaon An *elementary particle* (contraction of *K-meson*). A heavy *meson* with a mass about 970 times that of an electron. (See *meson.*)

kilo A prefix that multiplies a basic unit by 1000. (See Appendix.)

kiloton energy The energy of a nuclear explosion which is equivalent to that of an explosion of 1000 tons of TNT. (See *TNT equivalent, yield.*)

kinetic energy Energy due to motion.

L

label (See *tracer, isotopic.*)

lanthanide series The series of elements beginning with lanthanum, Element No. 57, and continuing through lutetium, Element No. 71, which together occupy one position in the *Periodic Table* of the elements. These are the "rare earths", which all have chemical properties similar to lanthanum. They also are called the "lanthanides". (Compare *actinide series;* see *rare earths.*) (See Appendix.)

lattice An orderly array or pattern of nuclear *fuel elements* and moderator in a reactor or critical assembly. Also, the arrangement of atoms in a crystal. (See *geometry.*)

leakage In nuclear engineering, the escape of neutrons from a reactor core. Leakage lowers a reactor's *reactivity.* (See *neutron economy.*)

lepton One of a class of light *elementary particles* (having small mass). Specifically, an electron, a positron, a neutrino, an antineutrino, a muon or an antimuon. (Compare *baryon, meson.*)

lethal dose A dose of *ionizing radiation* sufficient to cause death. Median lethal dose (MLD or LD-50) is the dose required to kill within a specified period of time (usually 30 days) half of the individuals in a large group of organisms similarly exposed. The LD-50/30 for man is about 400 – 450 roentgens. (See *biological dose, roentgen, survival curve, threshold dose.*)

licensed material *Source material, special nuclear material,* or *by-product material* received, possessed, used or transferred under a general or special license issued by the Atomic Energy Commission or a state.

light hydrogen Ordinary *hydrogen.*

light water Ordinary water (H_2O), as distinguished from *heavy water* (D_2O).

linac Short for *lin*ear *ac*celerator.

linear accelerator A long straight tube (or series of tubes) in which charged *particles* (ordinarily electrons or protons) gain in energy by the action of oscillating electromagnetic fields. (Compare *cyclotron;* see *accelerator.*)

linear energy transfer (Acronym LET) A measure of the ability of biological material to absorb *ionizing radiation;* the radiation energy lost per unit length of path through a biological material. In general, the higher the LET value, the greater is the relative biological effectiveness of the radiation in that material. (See *biological dose, relative biological effectiveness.*)

load factor The ratio of average load carried by an electric power plant or system during a specific period to its peak load during that period. (Compare *plant factor.*)

loop A closed circuit of pipe in which materials and components may be placed to test them under different conditions of temperature, irradiation, etc. If part of the loop and contents are placed in a reactor, it is called an *in-pile loop.*

low-level analysis (low-level counting) A procedure to measure the radioactive content of materials with very low levels of activity, using sensitive detecting instruments and with good shielding to eliminate the effects of *background radiation* and cosmic rays. (See *coincidence counting, counter.*)

low population zone An area of low population density sometimes required around a nuclear installation. The number and density of residents is of concern in providing, with reasonable probability, that effective *protection* measures can be taken if a serious accident should occur. (See *exclusion area.*)

luminescence Emission of light produced by the action of biological or chemical processes or by radiation, or any other cause except high temperature (which produces incandescence). (Compare *fluorescence, scintillation;* see *excited state, radioluminescence.*)

M

magnetic bottle A magnetic field used to confine or contain a plasma in controlled *fusion* (thermonuclear) experiments. (See *controlled thermonuclear reaction, plasma.*)

magnetic mirror A magnetic field used in controlled *fusion* experiments to reflect charged particles back into the central region of a *magnetic bottle.* (Compare *pinch effect;* see *controlled thermonuclear reaction.*)

Manhattan Project The War Department program during World War II that produced the first atomic bombs. The term originated in the code-name, "Manhattan Engineer District", which was used to conceal the nature of the secret work underway. The *Atomic Energy Commission,* a civilian agency, succeeded the military unit Jan. 1, 1947.

manipulators Mechanical devices used for safe handling of radioactive materials. Frequently they are remotely operated from behind a protective *shield.* (See *hot cell.*)

mass The quantity of *matter* in a body. Often used as a synonym for weight, which, strictly speaking, is the force exerted by a body under the influence of gravity. (See *atomic mass unit, atomic weight.*)

mass defect The difference between the *atomic mass* and the *mass number* of a nuclide. (See *packing fraction.*)

mass-energy equation (mass-energy equivalence) (mass-energy relation) The statement developed by Albert Einstein, German-born American physicist, that "the mass of a body is a measure of its energy content," as an extension of his 1905 *Special Theory of Relativity*. The statement was subsequently verified experimentally by measurements of mass and energy in nuclear reactions. The equation, usually given as: $E = mc^2$, shows that when the energy of a body changes by an amount, E, (no matter what form the energy takes) the mass, m, of the body will change by an amount equal to E/c^2. (The factor c^2, the square of the speed of light in a vacuum, may be regarded as the conversion factor relating units of mass and energy.) This equation predicted the possibility of releasing enormous amounts of energy (in the *atomic bomb*) by the conversion of mass to energy. It is also called the *Einstein equation.*

mass number [Symbol A] The sum of the neutrons and protons in a *NUCLEUS.* It is the nearest whole number to an atom's *atomic weight.* For instance, the mass number of uranium-235 is 235. (Compare *atomic number.*)

mass spectrograph, mass spectrometer Two related devices for detecting and analyzing *isotopes.* They separate nuclei that have different charge-to-mass ratios by passing the nuclei through electrical and magnetic fields. (See *isotope separation.*)

matter The substance of which a physical object is composed. All materials in the universe have the same inner nature, that is, they are composed of atoms, arranged in different (and often complex) ways; the specific atoms and the specific arrangements identify the various materials. (See *atom, element.*)

maximum credible accident The most serious reactor accident that can reasonably be imagined from any adverse combination of equipment malfunction, operating errors, and other foreseeable causes. The term is used to analyze the safety characteristics of a reactor. Reactors are designed to be safe even if a maximum credible accident should occur.

maximum permissible concentration (MPC) The amount of radioactive material in air, water, or food which might be expected to result in a *maximum permissible dose* to persons consuming them at a standard rate of intake. An obsolescent term. (See *radiation protection guide, radioactivity concentration guide.*)

maximum permissible dose (MPD) (maximum permissible exposure) That dose of *ionizing radiation* established by competent authorities as an amount below which there is no reasonable expectation of risk to human health, and which at the same time is somewhat below the lowest level at which a definite hazard is believed to exist. An obsolescent term. (See *radiation protection guide.*)

mean free path The average distance traveled by a particle, atom, or molecule between collisions or interactions. (See *collision.*)

mean life The average time during which an atom, an excited nucleus, a radionuclide or a particle exists in a particular form. (See *scattering.*)

median lethal dose (See *lethal dose.*)

mega A prefix that multiplies a basic unit by one million. (See Appendix.)

megaton energy The energy of a nuclear explosion which is equivalent to that of an explosion of one million tons (or 1000 kilotons) of TNT. (See *TNT equivalent, yield.*)

megawatt-day per ton A unit used for expressing the burnup of fuel in a reactor; specifically, the number of megawatt-days of heat output per metric ton of fuel in the reactor. (See *burnup.*)

meson One of a class of medium-mass, short-lived *elementary particles* with a mass between that of the electron and that of the proton. Examples: pi-mesons (*pions*) and K-mesons (*kaons*). (Compare *baryon, lepton.*)

Mev One million (or 10^6) electron volts. (Also written as MeV.) (See *electron volt.*) (See Appendix.)

micro A prefix that divides a basic unit by one million. (See Appendix.)

micromicro (See *pico.*)

milli A prefix that divides a basic unit by one thousand. (See Appendix.)

moderator A material, such as ordinary water, heavy water or graphite, used in a *reactor* to slow down high-velocity neutrons, thus increasing the likelihood of further *fission.* (Compare *reflector;* see *absorber, thermal neutrons.*)

molecule A group of atoms held together by chemical forces. The atoms in the molecule may be identical, as in H_2, S_2, and S_8, or different, as in H_2O and CO_2. A molecule is the smallest unit of matter which can exist by itself and retain all its chemical properties. (Compare *atom, ion.*)

molten salt reactor A *fused-salt reactor.*

monitor An instrument that measures the level of *ionizing radiation* in an area. (See *radiation detection instrument, radiation monitoring.*)

multiplication factor (or constant) [Symbol k] The ratio of the number of neutrons present in a reactor in any one neutron generation to that in the immediately preceding generation. *Criticality* is achieved when this ratio is equal to one. The "infinite" multiplication factor is the ratio in a theoretical system from which there is no leakage, that is, a reactor of infinite size; for an actual reactor (from which leakage does occur), the term *effective multiplication factor,* which is the ratio based on neutrons available after leakage, is commonly used. (See *generation time, leakage, neutron, reactivity.*)

mu-meson (See *muon.*)

muon (Contraction of *mu-meson.*) An *elementary particle,* classed as a lepton (not as a meson), with 207 times the mass of an electron. It may have a single positive or negative charge. (See *lepton, meson.*)

mushroom cloud (See *atomic cloud.*)

mutation A permanent transmissible change in the characteristics of an offspring from those of its parents. (Compare *radiomutation.*)

N

nano A prefix that divides a basic unit by one billion (10^9). (See Appendix.)

natural circulation reactor A reactor in which the *coolant* (usually water) is made to circulate without pumping, that is, by natural convection resulting from the different densities of its cold and reactor-heated portions.

natural radiation, natural radioactivity *background radiation.*

natural uranium Uranium as found in nature, containing 0.7% of ^{235}U, 99.3% of ^{238}U, and a trace of ^{234}U. It is also called *normal uranium.* (See *uranium.*)

negative temperature coefficient (See *temperature coefficient of reactivity.*)

neptunium series (sequence) The series of nuclides resulting from the radioactive decay of the man-made nuclide, neptunium-237. Many other man-made nuclides decay into this sequence. The end-product of the series is stable bismuth-209, which is the only nuclide in the series that occurs in nature. (See *decay, radioactive; radioactive series.*) (See Appendix.)

neutrino [Symbol ν (nu)] An electrically neutral *elementary particle* with a negligible mass. It interacts very weakly with matter and hence is difficult to detect. It is produced in many nuclear reactions, for example, in beta decay, and has high penetrating power; neutrinos from the sun usually pass right through the earth. (See *cosmic rays, neutron, nuclear reaction.*)

neutron [Symbol n] An uncharged *elementary particle* with a mass slightly greater than that of the *proton*, and found in the *nucleus* of every atom heavier than hydrogen. A free neutron is unstable and decays with a half-life of about 13 minutes into an electron, proton, and neutrino. Neutrons sustain the fission *chain reaction* in a *nuclear reactor*. (See *fast neutron, intermediate neutron,* and *thermal neutron.*)

neutron activation analysis *Activation analysis* in which neutrons are the activating agent.

neutron capture The process in which an atomic *nucleus* absorbs or captures a neutron. The probability that a given material will capture neutrons is measured by its neutron capture *cross section,* which depends on the energy of the neutrons and on the nature of the material. (See *capture, nuclear reaction, radiative capture.*)

neutron density The number of neutrons per cubic centimeter in the core of a reactor. (See *flux.*)

neutron economy The degree to which neutrons in a *reactor* are used for desired ends instead of being lost by leakage or nonproductive absorption. The ends may include propagation of the chain reaction, converting fertile to fissionable material, producing isotopes, or research. (See *leakage, reactivity.*)

neutron flux (See *flux.*)

nondestructive testing Testing to detect internal and concealed defects in materials using techniques that do not damage or destroy the items being tested. X rays, isotopic radiation and ultrasonics are frequently used.

normal uranium *natural uranium.*

nuclear battery A *radioisotopic generator.*

nuclear energy The energy liberated by a nuclear reaction (fission or fusion) or by radioactive decay. (See *decay, radioactive; fission; fusion; nuclear explosive; nuclear reactor.*)

nuclear explosive An explosive based on *fission* or *fusion* of atomic *nuclei.* (See *device, nuclear; nuclear weapons.*)

nuclear fission (See *fission.*)

nuclear fusion (See *fusion.*)

nuclear power plant Any device, machine, or assembly that converts nuclear energy into some form of useful power, such as mechanical or electrical power. In a nuclear electric power plant, heat produced by a *reactor* is generally used to make steam to drive a turbine that in turn drives an electric generator.

nuclear reaction A reaction involving a change in an atomic nucleus, such as *fission, fusion, neutron capture,* or *radioactive decay,* as distinct from a chemical reaction, which is limited to changes in the electron structure surrounding the nucleus. (Compare *thermonuclear reaction.*)

nuclear reactor A device in which a fission *chain reaction* can be initiated, maintained, and controlled. Its essential component is a *core* with fissionable *fuel.* It usually has a *moderator,* a *reflector, shielding, coolant,* and control mechanisms. Sometimes called an atomic "furnace", it is the basic machine of *nuclear energy.* (See *fission.*)

nuclear rocket A rocket powered by an engine that obtains energy for heating a propellant fluid (such as hydrogen) from a nuclear reactor, rather than from chemical combustion. (See *Rover.*)

nuclear superheating Superheating the steam produced in a reactor by using additional heat from a reactor. Two methods are commonly employed: recirculating the steam through the same core in which it is first produced (integral superheating) or passing the steam through a second and separate reactor. (See *superheating.*)

nuclear weapons A collective term for *atomic bombs* and *hydrogen bombs.* Any weapons based on a *nuclear explosive.* (Compare *device, nuclear.*)

nuclei Plural of *nucleus.*

nucleon A constituent of an atomic *nucleus,* that is, a *proton* or a *neutron.*

nucleonics The science and technology of nuclear energy and its applications.

nucleus The small, positively charged core of an *atom.* It is only about $^{1}/_{10,000}$ the diameter of the atom but contains nearly all the atom's mass. All nuclei contain both *protons* and *neutrons,* except the nucleus of ordinary hydrogen, which consists of a single proton.

nuclide A general term applicable to all atomic forms of the elements. The term is often erroneously used as a synonym for "isotope", which properly has a more limited definition. Whereas isotopes are the various forms of a single element (hence are a family of nuclides) and all have the same *atomic number* and number of protons, nuclides comprise *all* the isotopic forms of *all* the elements. Nuclides are distinguished by their *atomic number, atomic mass,* and energy state. (Compare *element, isotope.*) (See Appendix.)

O

open-cycle reactor system A reactor system in which the *coolant* passes through the reactor core only once and is then discarded. (Compare *closed-cycle reactor system.*)

orange oxide *uranium trioxide.*

orbit The region occupied by an *electron* as it moves about the *nucleus* of an *atom.* (See *shell.*)

organic-cooled reactor A reactor that uses organic chemicals, such as mixtures of polyphenyls (diphenyls and terphenyls), as coolant.

overpressure The transient pressure over and above atmospheric pressure caused by a shock wave from a nuclear explosion. (See *shock wave.*)

P

package power reactor A small nuclear power plant designed to be crated in packages small enough to be conveniently transported to remote locations.

packing fraction The difference between the actual mass of a nuclide and the nearest whole number, divided by the *mass number, A;* or $(M-A)/A$. An equivalent statement is that it is the *mass defect* divided by the mass number. It is positive for most nuclides with mass number less than 12 and more than 180, which therefore tend to be less stable, and negative for most other nuclides, which tend to be more stable.

pair production The transformation of the kinetic energy of a high-energy *photon* or *particle* into mass, producing a *particle* and its *antiparticle,* such as an *electron* and *positron.* (Compare *ion pair;* see *mass-energy equivalence.*)

parasitic capture Any absorption (as in a reactor) of neutrons in reactions which do not cause further fission or the production of new fissionable material. In a reactor the process is undesirable. (See *absorption, capture, neutron economy.*)

parent A radionuclide that upon radioactive decay or disintegration yields a specific nuclide (the daughter), either directly or as a later member of a radioactive series. (See *daughter, radioactive series.*) (See Appendix.)

particle A minute constituent of *matter,* generally one with a measurable mass. The primary particles involved in radioactivity are *alpha particles, beta particles, neutrons,* and *protons.* (Compare *antiparticle, photon;* see *charged particle, elementary particles, ion, radiation.*)

particle accelerator An *accelerator.*

pebble bed reactor A reactor in which the fissionable fuel (and sometimes also the moderator) is in the form of packed or randomly placed pellets, which are cooled by gas or liquid.

penetrometer A simple device for measuring the penetrating power of a beam of X rays or other penetrating *RADIATION* by comparing transmission through various absorbers. (See *absorber.*)

period The time required for one cycle of a regularly repeated series of events. In a nuclear reactor, it is the time required for the power level to change by the factor 2.718, which is known as e (the base of natural logarithms). (See *Periodic Table.*)

Periodic Table (Periodic Chart) A table or chart listing all the *elements,* arranged in order of increasing *atomic numbers* and grouped by similar physical and chemical characteristics into "periods". The table is based on the chemical law that the physical or chemical properties of the elements are periodic (regularly repeated) functions of their *atomic weights,* first proposed by the Russian chemist, Dmitri I. Mendeleev, in 1869. (See Appendix.)

permissible dose (See *maximum permissible dose, radiation protection guide.*)

personnel monitoring Determination by either physical or biological measurement of the amount of *ionizing radiation* to which an individual has been exposed, such as by measuring the darkening of a *film badge* or performing a *radon breath analysis.* (Compare *radiation monitoring;* see *hand and foot counter.*)

phantom A volume of material approximating as closely as possible the density and effective atomic number of living tissue, used in biological experiments involving radiation.

phosphor A luminescent substance; a material capable of emitting light when stimulated by radiation. (See *scintillation.*)

photon The carrier of a quantum of electromagnetic *energy.* Photons have an effective momentum but no mass or electrical charge. (See *radiation, quantum.*)

pico A prefix that divides a basic unit by one trillion (10^{12}). Same as *micromicro.* (See Appendix.)

pig A heavily shielded container (usually lead) used to ship or store radioactive materials.

pile Old term for *nuclear reactor.* This name was used because the first reactor was built by piling up graphite blocks and natural uranium.

pi-meson (See *pion.*)

pinch effect In controlled *fusion* experiments, the effect obtained when an electric current, flowing through a column of plasma, produces a magnetic field that confines and compresses the plasma. (Compare *magnetic bottle;* see *controlled thermonuclear reaction, plasma, Sherwood.*)

pion An *elementary particle* (contraction of *pi-meson*). The mass of a charged (positive or negative) pion is about 273 times that of an electron; that of an electrically neutral pion is 264 times that of an electron. (See *meson.*)

plant factor The ratio of the average power load of an electric power plant to its rated capacity. Sometimes called *capacity factor.* (Compare *load factor.*)

plasma An electrically neutral gaseous mixture of positive and negative *ions.* Sometimes called the "fourth state of matter", since it behaves differently from solids, liquids and gases. High-temperature plasmas are used in *controlled fusion experiments.* (See *charged particle.*)

Plowshare The Atomic Energy Commission program of research and development on peaceful uses of *nuclear explosives.* The possible uses include large-scale excavation, such as for canals and harbors, crushing ore bodies, and producing heavy transuranic isotopes. The term is based on a Biblical reference: *Isaiah 2: 4.*

plutonium [Symbol Pu] A heavy, radioactive, man-made, metallic element with atomic number 94. Its most important isotope is fissionable plutonium-239, produced by neutron irradiation of uranium-238. It is used for reactor fuel and in weapons. (See Appendix.)

poison Any material of high absorption *cross section* that absorbs neutrons unproductively and hence removes them from the fission chain reaction in a reactor, decreasing its *reactivity.* (Compare *burnable poison.*)

pool reactor A reactor in which the fuel elements are suspended in a pool of water that serves as the reflector, moderator, and coolant. Popularly called a swimming pool reactor, it is usually used for research and training. (Compare *tank reactor.*)

port An opening in a *research reactor* through which objects are inserted for irradiation or from which *beams* of radiation emerge for experimental use.

positive temperature coefficient (See *temperature coefficient of reactivity.*)

positron [Symbol β^+ (beta-plus)] An *elementary particle* with the mass of an electron but charged positively. It is the "antielectron". It is emitted in some radioactive disintegrations and is formed in pair production by the interaction of high-energy gamma rays with matter. (See *antimatter, electron, pair production.*)

power density The rate of heat generated per unit volume of a *reactor* core. (See *specific power.*)

power reactor A reactor designed to produce useful nuclear power, as distinguished from reactors used primarily for research or for producing radiation or fissionable materials. (Compare *production reactor, research reactor.*)

pressure suppression (See *vapor suppression.*)

pressure-tube reactor A reactor in which the fuel elements are located inside tubes containing coolant circulating at high pressure. The tube assembly is surrounded by a tank containing the moderator at low pressure.

pressure vessel A strong-walled container housing the core of most types of power reactors; it usually also contains moderator, reflector, thermal shield, and control rods. (Compare *containment vessel.*)

pressurized water reactor A power reactor in which heat is transferred from the core to a heat exchanger by water kept under high pressure to achieve high temperature without boiling in the primary system. Steam is generated in a secondary circuit. Many reactors producing electric power are pressurized water reactors.

primary fission products *fission fragments.*

probability (See *cross section.*)

process heat reactor A reactor that produces heat for use in manufacturing processes.

production reactor A reactor designed primarily for large-scale production of plutonium-239 by neutron *irradiation* of uranium-238. Also a reactor used primarily for the production of radioactive isotopes. (Compare *power reactor, research reactor.*)

prompt criticality The state of a reactor when the fission *chain reaction* is sustained solely by *prompt neutrons,* that is, without the help of *delayed neutrons.* (See *criticality.*)

prompt neutrons Neutrons that are emitted immediately following nuclear *fission,* as distinct from delayed neutrons, which are emitted for some time after fission has occurred. Prompt neutrons comprise more than 99% of fission neutrons. (Compare *delayed neutrons.*)

prompt radiation Radiation produced by the primary fission or fusion process, as distinguished from the radiation from *fission products,* their *decay chains* and other later reactions.

protection Provisions to reduce exposure of persons to radiation. For example, protective barriers to reduce external radiation or measures to prevent inhalation of radioactive materials. (See *radiation protection.*)

protective action guide (PAG) The *absorbed dose* of *ionizing radiation* to individuals in the general population which would warrant protective action following a contaminating event, such as a nuclear explosion. (See *radiation protection guide.*)

protective clothing Special clothing worn by a radiation worker to prevent contamination of his body or his personal clothing.

protective survey An evaluation of the radiation hazards incidental to the production, use, or existence of radioactive materials or other sources of radiation under a specific set of conditions.

proton An *elementary particle* with a single positive electrical charge and a mass approximately 1837 times that of the *electron.* The nucleus of an ordinary or light hydrogen *atom.* Protons are constituents of all nuclei. The *atomic number* (Z) of an atom is equal to the number of protons in its *nucleus.*

proton synchrotron A type of particle *accelerator* for producing beams of very high energy protons (in the Bev range).

pulse An electrical signal arising from a single event of *ionizing radiation.*

pulse amplifier An amplifier designed specifically to amplify the intermittent signals of a radiation detection instrument, incorporating appropriate pulse-shaping characteristics.

pulse height The measure of the strength or signal amplitude of a pulse delivered by a detector; measured in volts.

pulse height analyzer An electronic circuit which sorts and records pulses according to height or voltage.

pulse height discriminator (See *discriminator.*)

pulse height selector A circuit designed to select and pass voltage pulses in a certain range of amplitudes.

pulsed reactor A type of research reactor with which repeated short, intense surges of power and radiation can be produced. The *neutron flux* during each surge is much higher than could be tolerated during a steady-state operation.

Q

Q A unit used to express very large energy figures. One *Q* equals 10^{18} (1 billion billion) BTU (British thermal units).

quality factor The factor by which absorbed dose is to be multiplied to obtain a quantity that expresses on a common scale, for all ionizing radiations, the irradiation incurred by exposed persons. (See *dose equivalent, distribution factor, relative biological effectiveness.*)

quantum Unit quantity of energy according to the *quantum theory*. It is equal to the product of the frequency of radiation of the energy and 6.6256×10^{-27} erg-sec. The *photon* carries a quantum of electromagnetic energy. (See *electromagnetic radiation, radiation.*) (See Planck's constant in Appendix.)

quantum theory The statement according to Max Planck, German physicist, that energy is not emitted or absorbed continuously but in units or quanta. A corollary of this theory is that the energy of radiation is directly proportional to its frequency. (See *quantum.*)

quench To limit or stop the electrical discharge in an *ionization* detector.

R

rabbit A device to move a sample rapidly from one place (such as inside a research reactor) to another place (such as a radiochemistry laboratory). "Rabbits" often consist of small cylinders of aluminum or plastic, moved by air pressure through a long pipe.

rad (Acronym for *r*adiation *a*bsorbed *d*ose.) The basic unit of absorbed dose of *ionizing radiation*. A dose of one rad means the absorption of 100 ergs of radiation energy per gram of absorbing material. (Compare *rem, roentgen;* see *absorbed dose.*)

radiation The emission and propagation of *energy* through matter or space by means of electromagnetic disturbances which display both wave-like and particle-like behavior; in this context the "particles" are known as *photons*. Also, the energy so propagated. The term has been extended to include streams of fast-moving *particles* (alpha and beta particles, free neutrons, cosmic radiation, etc.). Nuclear radiation is that emitted from atomic nuclei in various *nuclear reactions*, including alpha, beta and gamma radiation and neutrons. (See *electromagnetic radiation, ionizing radiation, quantum.*)

radiation accidents Accidents resulting in the spread of radioactive material or in the exposure of individuals to radiation.

radiation area Any accessible area in which the level of radiation is such that a major portion of an individual's body could receive in any one hour a dose in excess of 5 millirem, or in any 5 consecutive days a dose in excess of 150 millirem. (See *absorbed dose, rem.*)

radiation biology (See *radiobiology*).

radiation burn Radiation damage to the skin. Beta burns result from skin contact with or exposure to emitters of beta particles. Flash burns result from sudden thermal radiation. (See *beta particles, flash burn, ionizing radiation, thermal burn.*)

radiation chemistry The branch of chemistry that is concerned with the chemical effects, including decomposition, of energetic radiation or particles on matter. (Compare *radiochemistry.*)

radiation damage A general term for the harmful effects of radiation on matter.

radiation detection instruments Devices that detect and record the characteristics of *ionizing radiation.* (See *counter, dosimeter, monitor.*)

radiation dosimetry The measurement of the amount of radiation delivered to a specific place or the amount of radiation that was absorbed there. (See *dosimeter.*)

radiation illness An acute organic disorder that follows exposure to relatively severe doses of ionizing radiation. It is characterized by nausea, vomiting, diarrhea, blood cell changes, and in later stages by hemorrhage and loss of hair. (See *ionizing radiation.*)

radiation monitoring Continuous or periodic determination of the amount of radiation present in a given area. (See *monitor.*)

radiation protection Legislation and regulations to protect the public and laboratory or industrial workers against radiation. Also measures to reduce exposure to radiation. (Compare *protection;* see *radiation standards.*)

radiation protection guide The officially determined radiation doses which should not be exceeded without careful consideration of the reasons for doing so. These standards, established by the Federal Radiation Council, are equivalent to what was formerly called the *maximum permissible dose* or *maximum permissible exposure.* (See *radioactivity concentration guide.*)

radiation shielding Reduction of radiation by interposing a shield of absorbing material between any radioactive source and a person, laboratory area, or radiation-sensitive device. (See *absorber, shield.*)

radiation source Usually a man-made, sealed source of *radioactivity* used in teletherapy, radiography, as a power source for batteries, or in various types of industrial gauges. Machines such as accelerators, and radioisotopic generators and natural radionuclides may also be considered as sources.

radiation standards Exposure standards, permissible concentrations, rules for safe handling, regulations for transportation, regulations for industrial control of radiation, and control of radiation exposure by legislative means. (See *radiation protection, radiation protection guide.*)

radiation sterilization Use of radiation to cause a plant or animal to become sterile, that is, incapable of reproduction. Also the use of radiation to kill all forms of life (especially bacteria) in food, surgical sutures, etc. (Compare *radiation illness, radiomutation.*)

radiation therapy Treatment of disease with any type of radiation. Often called radiotherapy. (See *brachytherapy, teletherapy.*)

radiation warning symbol

An officially prescribed symbol (a magenta trefoil on a yellow background) which should always be displayed when a radiation hazard exists.

radiations Specific units or types of radiation.

radiative capture A nuclear capture process whose prompt result is emission of electromagnetic radiation only, as when a *NUCLEUS* captures a neutron and emits gamma rays. (See *capture.*)

radio- A prefix denoting *radioactivity* or a relationship to it, or a relationship to *radiation.*

radioactivation *activation.*

radioactive Exhibiting radioactivity or pertaining to radioactivity.

radioactive chain A *radioactive series.*

radioactive cloud A mass of air and vapor in the atmosphere carrying radioactive debris from a nuclear explosion. (See *atomic cloud.*)

radioactive contamination Deposition of radioactive material in any place where it may harm persons, spoil experiments, or make products or equipment unsuitable or unsafe for some specific use. The presence of unwanted radioactive matter. Also radioactive material found on the walls of vessels in used-fuel processing plants, or radioactive material that has leaked into a reactor coolant. Often referred to only as *contamination.* (Compare *background radiation;* see *decontamination.*)

radioactive dating A technique for measuring the age of an object or sample of material by determining the ratios of various *radioisotopes* or products of radioactive decay it contains. For example, the ratio of carbon-14 to carbon-12 reveals the approximate age of bones, pieces of wood, or other archeological specimens that contain carbon extracted from the air at the time of their origin. (Compare *atomic clock;* see *decay, radioactive.*)

radioactive decay (disintegration) (See *decay, radioactive.*)

radioactive fallout (See *fallout.*)

radioactive half-life (See *half-life.*)

radioactive isotope A *radioisotope.*

radioactive series A succession of nuclides, each of which transforms by radioactive disintegration into the next until a stable nuclide results. The first member is called the *parent*, the intermediate members are called *daughters*, and the final stable member is called the *end product*. (See *decay, radioactive.*) (See Appendix.)

radioactive source A *radiation source.*

radioactive standard A sample of radioactive material, usually with a long half-life, in which the number and type of radioactive atoms at a definite reference time is known. These are used in calibrating radiation measuring equipment or for comparing measurements in different laboratories. (Compare *radiation source.*)

radioactive tracer A small quantity of radioactive *isotope* (either with carrier or carrier-free) used to follow biological, chemical or other processes, by detection, determination or localization of the radioactivity. (See *carrier; tracer, isotopic.*)

radioactive waste (See *waste, radioactive.*)

radioactivity The spontaneous decay or disintegration of an unstable atomic *nucleus*, usually accompanied by the emission of *ionizing radiation*. (Often shortened to "activity".) (See *decay, radioactive.*) (See Appendix.)

radioactivity concentration guide The concentration of radioactive material in an environment which would result in doses equal, over a period of time, to those in the *Radiation Protection Guide*. This Federal Radiation Council term replaces the former *maximum permissible concentration.*

radiobiology The body of knowledge and the study of the principles, mechanisms, and effects of ionizing radiation on living matter.

radiochemistry The body of knowledge and the study of the chemical properties and reactions of radioactive materials. (Compare *radiation chemistry.*)

radioecology The body of knowledge and the study of the effects of radiation on species of plants and animals in natural communities.

radioelement An element containing one or more radioactive *isotopes;* a *radioactive* element.

radiogenic Of radioactive origin; produced by radioactive *transformation.* (See *decay, radioactive; transmutation.*)

radiography The use of ionizing radiation for the production of shadow images on a photographic emulsion. Some of the rays (*gamma rays* or *X rays*) pass through the subject, while others are partially or completely absorbed by the more opaque parts of the subject and thus cast a shadow on the photographic film. (Compare *autoradiograph.*)

radioisotope A radioactive isotope. An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation. More than 1300 natural and artificial radioisotopes have been identified. (See *decay, radioactive; isotope.*) (See Appendix.)

radioisotopic generator A small power generator that converts the heat released during radioactive decay directly into electricity. These generators generally produce only a few watts of electricity and use thermoelectric or thermionic converters. Some also function as electrostatic converters to produce a small voltage. Sometimes called an "atomic battery". (See *decay, radioactive; SNAP.*)

radiology The science which deals with the use of all forms of ionizing radiation in the diagnosis and the treatment of disease. (Compare *radioactive tracer, radiography.*)

radioluminescence Visible light caused by radiations from radioactive substances; an example is the glow from luminous paint containing radium and crystals of zinc sulfide, which give off light when struck by alpha particles from the radium. (See *luminescence.*)

radiolysis The dissociation (or decomposition) of molecules by radiation. Example: A small proportion of water in a reactor core dissociates into hydrogen and oxygen during operation of the reactor.

radiomimetic substances Chemical substances which cause biological effects similar to those caused by ionizing radiation.

radiomutation A permanent, transmissible change in form, quality, or other characteristic of a cell or offspring from the characteristics of its parent, due to radiation exposure. (See *genetic effects of radiation, mutation.*)

radionuclide A *radioactive nuclide.*

radioresistance A relative resistance of cells, tissues, organs, or organisms to the injurious action of radiation. (Compare *radiosensitivity.*)

radiosensitivity A relative susceptibility of cells, tissues, organs or organisms to the injurious action of radiation. (Compare *radioresistance.*)

radiotherapy *radiation therapy.*

radium [Symbol Ra] A radioactive metallic element with atomic number 88. As found in nature, the most common isotope has an atomic weight of 226. It occurs in minute quantities associated with uranium in pitchblende, carnotite and other minerals; the uranium decays to radium in a series of alpha and beta emissions. By virtue of being an alpha- and gamma-emitter, radium is used as a source of *luminescence* and as a *radiation source* in medicine and radiography. (See Appendix.)

radon [Symbol Rn] A radioactive element, one of the heaviest gases known. Its atomic number is 86, and its atomic weight is 222. It is a *daughter* of radium in the uranium *radioactive series.* (See Appendix.)

radon breath analysis Examination of exhaled air for the presence of radon to determine the presence and quantity of *radium* in the human body. (See *personnel monitoring.*)

rare earths A group of 15 chemically similar metallic elements, including Elements 57 through 71 on the *Periodic Table* of the Elements, also known as the Lanthanide Series. (See *lanthanide series.*) (See Appendix.)

reactivity A measure of the departure of a nuclear reactor from criticality. It is about equal to the effective multiplication factor minus one and is thus precisely zero at criticality. If there is excess reactivity (positive reactivity), the reactor is supercritical and its power will rise. Negative reactivity (subcriticality) will result in a decreasing power level. (See *criticality, dollar, excess reactivity, multiplication factor, subcritical assembly, supercritical reactor.*)

reactor (See *nuclear reactor.*)

recycling The reuse of *fissionable material,* after it has been recovered by chemical processing from spent or depleted reactor fuel, reenriched, and then refabricated into new fuel elements. (See *fuel cycle, fuel reprocessing, spent fuel.*)

reflector A layer of material immediately surrounding a reactor core which scatters back or reflects into the core many neutrons that would otherwise escape. The returned neutrons can then cause more fissions and improve the *neutron economy* of the reactor. Common reflector materials are graphite, beryllium and natural uranium. (Compare *moderator.*)

regulating rod A reactor *control rod* used for making frequent fine adjustments in reactivity. (Compare *shim rod.*)

relative biological effectiveness (RBE) A factor used to compare the biological effectiveness of different types of *ionizing radiation.* It is the inverse ratio of the amount of absorbed radiation, required to produce a given effect, to a standard (or reference) radiation required to produce the same effect. (See *absorbed dose, distribution factor, quality factor, rad, rem.*)

rem (Acronym for *r*oentgen *e*quivalent *m*an.) The unit of dose of any ionizing radiation which produces the same biological effect as a unit of *absorbed dose* of ordinary X rays. The RBE dose (in *rems*) = RBE × absorbed dose (in *rads*). (Compare *curie, roentgen.*)

rep (Acronym for *r*oentgen *e*quivalent *p*hysical.) An obsolete unit of absorbed dose of any ionizing radiation, with a magnitude of 93 ergs per gram. It has been superseded by the *rad.*

reprocessing *fuel reprocessing.*

research reactor A reactor primarily designed to supply neutrons or other ionizing radiation for experimental purposes. It may also be used for training, materials testing, and production of radioisotopes. (Compare *experimental reactor, power reactor, production reactor, test reactor.*)

residence time The time during which radioactive material remains in the atmosphere following the detonation of a nuclear explosive. It is usually expressed as a *half-time,* since the time for all material to leave the atmosphere is not well known. (Compare *half-life*; see *fallout.*)

residual nuclear radiation Lingering radiation, or radiation emitted by radioactive material remaining after a nuclear explosion. Residual radiation is arbitrarily designated as that emitted more than one minute after the explosion. (Compare *fallout, initial nuclear radiation.*)

resonance The phenomenon whereby *particles* such as neutrons exhibit a very high interaction probability with nuclei at specific kinetic energies of the particles. Cross sections for neutron capture and scattering, for example, exhibit peaks at these so-called resonance energies and have relatively low values between the peaks. (This term is also applied to several other phenomena in physics.) (See *capture, cross section, nuclear reaction, scattering.*)

rod A relatively long, slender body of material used in or in conjunction with a nuclear reactor. It may contain fuel, absorber, or material in which activation or transmutation is desired. (See *control rod.*)

roentgen [Abbreviation r] A unit of exposure to *ionizing radiation.* It is that amount of gamma or X rays required to produce ions carrying 1 electrostatic unit of electrical charge (either positive or negative) in 1 cubic centimeter of dry air under standard conditions. Named after Wilhelm Roentgen, German scientist who discovered X rays in 1895. (Compare *curie, rad, rem.*)

roentgen equivalent, man (See *rem.*)

roentgen rays *X rays.*

roentgen therapy *Radiation therapy* with X rays.

roentgenography *Radiography* by means of X rays.

Rover A joint program of the Atomic Energy Commission and the National Aeronautics and Space Administration to develop a nuclear rocket for space flight. (See *nuclear rocket.*)

S

safety rod A standby *control rod* used to shut down a nuclear reactor rapidly in emergencies. (See *scram.*)

scaler An electronic instrument for rapid counting of radiation-induced *pulses* from Geiger counters or other radiation detectors. It permits rapid counting by reducing (by a definite scaling factor) the number of pulses entering the counter. (See *counter, Geiger-Müller counter.*)

scanner (See *scanning, radioisotope.*)

scanning, radioisotope A method of determining the location and amount of radioactive isotopes within the body by measurements taken with instruments outside the body; usually the instrument, called a scanner, moves in a regular pattern over the area to be studied, or over the whole body, and makes a visual record. (Compare *whole-body counter;* see *coincidence counting.*)

scattering A process that changes a particle's trajectory. Scattering is caused by *particle* collisions with atoms, nuclei, and other particles or by interactions with fields of magnetic force. If the scattered particle's internal energy (as contrasted with its kinetic energy) is unchanged by the collision, elastic scattering prevails; if there is a change in the internal energy, the process is called inelastic scattering. (See *collision, Compton effect.*)

scavenging In chemistry, the use of a nonspecific precipitate to remove one or more undesirable radionuclides from solution by absorption or coprecipitation. In atmospheric physics, the removal of radionuclides from the atmosphere by the action of rain, snow or dew. (See *fallout.*)

scintillation A flash of light produced in a *phosphor* by an *IONIZING EVENT.* (Compare *fluorescence, luminescence.*)

scintillation counter An instrument that detects and measures ionizing radiation by counting the light flashes (scintillations) caused by radiation impinging on certain materials (*phosphors*).

scram The sudden shutdown of a nuclear reactor, usually by rapid insertion of the *safety rods.* Emergencies or deviations from normal reactor operation cause the reactor operator or automatic control equipment to scram the reactor.

Seebeck effect The phenomenon involved in the operation of a thermocouple. It is named for the German scientist Thomas Seebeck, who first observed the phenomenon in 1822. (See *thermocouple.*)

seed (See *seed core.*)

seed (and blanket) core A reactor core which includes a relatively small volume of highly *enriched uranium* (the seed) surrounded by a much larger volume of *natural uranium* or thorium (the blanket). As a result of fissions in the seed, neutrons are supplied to the blanket where more fission takes place. In this way, the blanket is made to furnish a substantial fraction of the total power of the reactor. Also called a *spiked core.*

shell One of a series of concentric spheres, or *orbits,* at various distances from the *nucleus,* in which, according to atomic theory, *electrons* move around the nucleus of an *atom.* The shells are designated, in the order of increasing distance from the nucleus, as the *k, l, m, n, o, p,* and *q* shells. The number of electrons which each shell can contain is limited. Electrons in each shell have the same energy level and are further grouped into subshells. (See *electron capture, K-capture.*) (See Appendix.)

Sherwood The Atomic Energy Commission program for research in *controlled thermonuclear reactions.*

shield (shielding) A body of material used to reduce the passage of radiation. (See *barricade shield, barrier shield, biological shield, radiation shielding, thermal shield.*)

shim rod A reactor control rod used in making infrequent coarse adjustments in reactivity, as in startup or shutdown. (Compare *regulating rod;* see *control rod, reactivity.*)

shock wave A pressure pulse in air, water or earth, propagated from an explosion, which has two phases: in the first, or positive phase, the pressure rises sharply to a peak, then subsides to the normal pressure of the surrounding medium; in the second, or negative phase, the pressure falls below that of the medium, then returns. A shock wave in air usually is called a *blast wave.*

single-cycle reactor system A *direct-cycle reactor system.*

slow neutron A *thermal neutron.*

slug A short, usually cylindrical *fuel element.*

SNAP (Acronym for *S*ystems for *N*uclear *A*uxiliary *P*ower.) An Atomic Energy Commission program to develop small auxiliary nuclear power sources for specialized space, land, and sea uses. Two approaches are employed: the first uses heat from radioisotope decay to produce electricity directly by thermoelectric or thermionic methods; the second uses heat from small reactors to produce electricity by thermoelectric or thermionic methods or by turning a small turbine and electric generator. (See *radioisotopic generator, thermionic conversion, thermoelectric conversion.*)

sodium-graphite reactor A reactor that uses liquid sodium as coolant and graphite as moderator.

somatic effects of radiation Effects of radiation limited to the exposed individual, as distinguished from genetic effects (which also affect subsequent, unexposed generations). Large radiation doses can be fatal. Smaller doses may make the individual noticeably ill, may merely produce temporary changes in blood-cell levels detectable only in the laboratory, or may produce no detectable effects whatever. Also called physiological effects of radiation. (Compare *genetic effects of radiation;* see *radiation illness.*)

source (See *radiation source.*)

source material In atomic energy law any material, except *special nuclear material,* which contains 0.05% or more of uranium, thorium, or any combination of the two. (See *licensed material, special nuclear material.*)

spark chamber An instrument for detecting and measuring the paths of *ELEMENTARY PARTICLES.* It is analogous to the cloud chamber and bubble chamber. It consists of numerous electrically charged metal plates mounted in a parallel array, the spaces between the plates being filled with an inert gas. Any *ionizing event* causes sparks to jump between the plates along the radiation path through the chamber. (Compare *bubble chamber, cloud chamber.*)

special nuclear material In atomic energy law, this term refers to plutonium-239, uranium-233, uranium containing more than the natural abundance of uranium-235, or any material artificially enriched in any of these substances. (Compare *source material;* see *enriched material, licensed material.*)

Special (or Restricted) Theory of Relativity A theory developed by Albert Einstein in 1905 that is of great importance in atomic and nuclear physics. It is especially useful in studies of objects moving with speeds approaching the speed of light. Two of the results of the theory with specific application in nuclear physics are statements (a) that the mass of an object increases with its velocity and (b) that mass and energy are equivalent. (See *mass-energy equation.*)

species A particular kind of atomic nucleus, atom, molecule or ion; a *nuclide.*

specific activity The radioactivity of a radioisotope of an element per unit weight of the element in a sample. The activity per unit mass of a pure radionuclide. The activity per unit weight of any sample of radioactive material. (See *radioactivity.*)

specific ionization The number of *ion pairs* formed per unit of distance along the track of an ion passing through matter. (See *ionization, ionizing radiation.*)

specific power The power generated in a nuclear reactor per unit mass of fuel. It is expressed in kilowatts of heat per kilogram of fuel. (See *power density.*)

spectral shift reactor A reactor design in which a mixture of light water and *heavy water* is used as the *moderator* and coolant. The ratio of light to heavy water is varied to change (shift) the speed distribution (*spectrum*) of the neutrons in the reactor core. Since the probability of neutron *capture* varies with neutron velocity, a measure of reactor control is thus obtained.

spectrum A visual display, a photographic record, or a plot of the distribution of the intensity of a given type of *radiation* as a function of its wave length, energy, frequency, momentum, mass, or any related quantity.

spent (depleted) fuel Nuclear reactor fuel that has been irradiated (used) to the extent that it can no longer effectively sustain a chain reaction. (Compare *depleted uranium;* see *burnup.*)

spiked core A *seed core.*

spill The accidental release of radioactive material.

spontaneous fission Fission that occurs without an external stimulus. Several heavy isotopes decay mainly in this manner; examples: californium-252 and californium-254. The process occurs occasionally in all fissionable materials, including uranium-235.

stable Incapable of spontaneous change. Not radioactive.

stable isotope An isotope that does not undergo radioactive decay. (Compare *radioisotope.*)

stopping power A measure of the effect of a substance upon the kinetic energy of a *charged particle* passing through it. (Compare *cross section;* see *absorption.*)

strange particles A class of very short-lived *elementary particles* that decay more slowly than they are formed, indicating that the production process and decay process result from different fundamental reactions. They include K-mesons and hyperons.

stress corrosion Chemical corrosion, such as of reactor pressure vessels, that is accelerated by stress concentrations, either built into or resulting from a load.

subatomic particle Any of the constituent particles of an atom: an electron, neutron, proton, etc.

subcritical assembly A reactor consisting of a mass of fissionable material and moderator whose effective multiplication factor is less than one and that hence cannot sustain a chain reaction. Used primarily for educational purposes. (See *criticality, multiplication factor, reactivity.*)

subcritical mass An amount of fissionable material insufficient in quantity or of improper geometry to sustain a fission chain reaction. (See *critical mass, criticality.*)

subcritical reactor A *subcritical assembly.*

supercritical mass A mass of fuel whose effective multiplication factor is greater than one. (See *critical mass, multiplication factor.*)

supercritical reactor A reactor in which the effective multiplication factor is greater than one; consequently a reactor that is increasing its power level. If uncontrolled, a supercritical reactor would undergo an excursion. (See *criticality, excursion, multiplication factor.*)

superheating The heating of a vapor, particularly saturated (wet) steam, to a temperature much higher than the boiling point at the existing pressure. This is done in power plants to improve efficiency and to reduce condensation in the turbines. (See *nuclear superheating.*)

surface contamination The deposition and attachment of radioactive materials to a surface. (See *radioactive contamination.*)

surface zero (See *ground zero.*)

survey meter Any portable *radiation detection instrument* especially adapted for surveying or inspecting an area to establish the existence and amount of radioactive material present. (Compare *counter, monitor.*)

survival curve Curve obtained by plotting the number or percentage of organisms surviving at a given time against the dose of radiation, or the number surviving at different intervals after a particular dose of radiation. (See *lethal dose.*)

swimming pool reactor A *pool reactor.*

synchrocyclotron A cyclotron in which the frequency of the accelerating voltage is decreased with time so as to match exactly the slowing revolutions of the accelerated particles. The decrease in rate of acceleration of the particles results from the increase of mass with energy as predicted by the *Special Theory of Relativity.* (Compare *synchrotron;* see *cyclotron.*)

synchrotron An *accelerator* in which particles are accelerated around a circular path by radio-frequency electric fields. The magnetic guiding and focusing fields are increased synchronously to match the energy gained by the particles so that the orbit radius remains constant. (Compare *cyclotron, synchrocyclotron.*)

T

tag (See *tracer, isotopic.*)

tails (See *depleted uranium.*)

tank reactor A reactor in which the core is suspended in a closed tank, as distinct from an open pool reactor. These are commonly used as research and test reactors. (Compare *pool reactor.*)

target Material subjected to particle bombardment (as in an *accelerator*) or irradiation (as in a research reactor) in order to induce a *nuclear reaction;* also a nuclide that has been bombarded or irradiated. (See *cross section, X ray.*)

teaching reactor A *research reactor* or *subcritical assembly.*

teletherapy Radiation treatment administered by using a *source* that is at a distance from the body, usually employing gamma-ray beams from radioisotope sources. (Compare *brachytherapy;* see *radiation therapy.*)

temperature coefficient of reactivity The change in reactor reactivity (per degree of temperature) occurring when the operating temperature changes. The coefficient is said to be positive when an increase in temperature increases the reactivity, negative when an increase in temperature decreases reactivity. Negative temperature coefficients are desirable because they help to prevent power excursions. (See *excursion, reactivity.*)

test reactor A reactor specially designed to test the behavior of materials and components under the neutron and gamma fluxes and temperature conditions of an operating reactor. (Compare *experimental reactor, research reactor.*)

thermal breeder reactor A breeder reactor in which the fission chain reaction is sustained by *thermal neutrons.*

thermal burn A burn of the skin or other organic material due to radiant heat, such as that produced by the detonation of a nuclear explosive. (See *flash burn, radiation burn, radiation illness.*)

thermal column A channel built into some research reactors to supply thermal neutrons for experimental purposes. It consists of a large body of *moderator* located adjacent to the core or reflector. Neutrons escaping from the reactor enter the thermal column where they are slowed down to thermal energies with velocities of about 2200 meters per second. (See *thermal neutron.*)

thermal efficiency The ratio of the electric power produced by a power plant to the amount of heat produced by the fuel; a measure of the efficiency with which the plant converts thermal to electrical energy.

thermal (slow) neutron A neutron in thermal equilibrium with its surrounding medium. Thermal neutrons are those that have been slowed down by a *moderator* to an average speed of about 2200 meters per second (at room temperature) from the much higher initial speeds they had when expelled by fission. This velocity is similar to that of gas molecules at ordinary temperatures. (Compare *fast neutron, intermediate neutron;* see *fission.*)

thermal radiation Electromagnetic radiation emitted from the fireball produced by a nuclear explosion. Thirty-five percent of the total energy of a nuclear explosion is emitted in the form of thermal radiation, as light, ultraviolet and infrared radiation.

thermal reactor A reactor in which the fission chain reaction is sustained primarily by thermal neutrons. Most reactors are thermal reactors. (Compare *fast reactor, intermediate reactor;* see *thermal neutron.*)

thermal shield A layer or layers of high density material located within a reactor pressure vessel or between the vessel and the biological shield to reduce radiation heating in the vessel and the biological shield. (See *biological shield, shield.*)

thermionic conversion The conversion of heat into electricity by evaporating electrons from a hot metal surface and condensing them on a cooler surface. No moving parts are required. (Compare *thermoelectric conversion.*)

thermocouple A device consisting essentially of two conductors made of different metals, joined at both ends, producing a loop in which an electric current will flow when there is a difference in temperature between the two junctions. (See *Seebeck effect, thermoelectric conversion.*)

thermoelectric conversion The conversion of heat into electricity by the use of thermocouples. (Compare *thermionic conversion;* see *thermocouple.*)

thermonuclear bomb (device) A *hydrogen bomb* (device).

thermonuclear reaction A reaction in which very high temperatures bring about the fusion of two light nuclei to form the nucleus of a heavier atom, releasing a large amount of energy. In a *hydrogen bomb,* the high temperature to initiate the thermonuclear reaction is produced by a preliminary *fission* reaction. (See *fusion, Sherwood.*)

thorium [Symbol Th] A naturally radioactive element with atomic number 90 and, as found in nature, an atomic weight of approximately 232. The fertile thorium-232 isotope is abundant and can be transmuted to fissionable uranium-233 by neutron irradiation. (See *fertile material, transmutation.*) (See Appendix.)

thorium series (sequence) The series of nuclides resulting from the radioactive decay of thorium-232. Many man-made nuclides decay into this sequence. The end product of this sequence in nature is lead-208. (See *decay, radioactive; radioactive series.*) (See Appendix.)

threshold dose The minimum dose of radiation that will produce a detectable biological effect. (See *absorbed dose, biological dose.*)

time-of-flight spectrometer A device for separating and sorting neutrons (or other particles) into categories of similar energy, measured by the time it takes the particles to travel a known distance. (Compare *mass spectrometer.*)

TNT equivalent A measure of the energy released in the detonation of a *nuclear explosive* expressed in terms of the weight of TNT (the chemical explosive, trinitrotoluene) which would release the same amount of energy when exploded. It is usually expressed in kilotons or megatons. The TNT equivalence relationship is based on the fact that 1 ton of TNT releases one billion (10^9) calories of energy. (See *kiloton energy, megaton energy, yield.*)

toll enrichment A proposed arrangement whereby privately owned uranium could be enriched in uranium-235 content in government facilities upon payment of a service charge by the owners. (See *isotopic enrichment, uranium.*)

tracer, isotopic An isotope of an element, a small amount of which may be incorporated into a sample of material (the carrier) in order to follow (trace) the course of that element through a chemical, biological or physical process, and thus also follow the larger sample. The tracer may be radioactive, in which case observations are made by measuring the radioactivity. If the tracer is stable, mass spectrometers, density measurement, or neutron activation analysis may be employed to determine isotopic composition. Tracers also are called *labels* or *tags*, and materials are said to be labeled or tagged when radioactive tracers are incorporated in them. (See *carrier, radioactive tracer.*)

transformation, nuclear *transmutation.*

transmutation The transformation of one element into another by a *nuclear reaction* or series of reactions. Example: the transmutation of uranium-238 into plutonium-239 by absorption of a neutron.

transplutonium element An element above *plutonium* in the *PERIODIC TABLE*, that is, one with an atomic number greater than 94. (See *transuranic element.*)

transuranic element (isotope) An element above *uranium* in the *PERIODIC TABLE*, that is, with an atomic number greater than 92. All 11 transuranic elements are produced artificially and are radioactive. They are neptunium, plutonium, americium, curium, berkelium, californium, einsteinium, fermium, mendelevium, nobelium, and lawrencium. (See Appendix.)

transuranium element A *transuranic element.*

triage The process of determining which casualties (from a large number of persons exposed to heavy radiation) need urgent treatment, which ones are well enough to go untreated, and which ones are beyond hope of benefit from treatment. Used in medical aspects of civil defense.

tritium A radioactive *isotope* of hydrogen with two neutrons and one proton in the nucleus. It is man-made and is heavier than deuterium (heavy hydrogen). Tritium is used in industrial thickness gauges, and as a label in experiments in chemistry and biology. Its nucleus is a *triton.* (Compare *deuterium;* see *hydrogen.*)

triton The nucleus of a tritium (^3H) atom. (See *hydrogen, tritium.*)

U

U-235 Uranium-235. (See *uranium.*) (See Appendix.)

unstable isotope A *radioisotope.* (Compare *stable isotope.*)

uranium [Symbol U] A radioactive element with the atomic number 92 and, as found in natural ores, an average atomic weight of approximately 238. The two principal natural isotopes are uranium-235 (0.7% of *natural uranium*), which is fissionable, and uranium-238 (99.3% of natural uranium) which is fertile. Natural uranium also includes a minute amount of uranium-234. Uranium is the basic raw material of nuclear energy. (See *fertile material, fissionable material, natural uranium.*) (See Appendix.)

uranium enrichment (See *isotopic enrichment.*)

uranium hexafluoride [Symbol UF_6] A volatile compound of uranium and fluorine. UF_6 gas is the process fluid in the *gaseous diffusion process.* (See *isotope separation.*)

uranium series (sequence) The series of nuclides resulting from the radioactive decay of uranium-238, also known as the uranium-radium series. The end product of the series is lead-206. Many man-made nuclides decay into this sequence. (See *decay, radioactive; radioactive series.*) (See Appendix.)

uranium tetrafluoride [Symbol UF_4] A solid green compound called *green salt.* An intermediate product in the production of uranium hexafluoride. (See *uranium hexafluoride.*)

uranium trioxide [Symbol UO_3] An intermediate product in the refining of uranium, also called *orange oxide.*

use charge An annual rental charge assessed by the Atomic Energy Commission for inventories of enriched fissionable material.

V

Van de Graaff generator (accelerator) An electrostatic machine in which electrically *charged particles* are sprayed on a moving belt and carried by it to build up a high potential on an insulated terminal. Charged particles are then accelerated along a discharge path through a vacuum tube by the potential difference between the insulated terminal and the opposite end of the machine. A Van de Graaff accelerator is often used to inject particles into larger accelerators. Named after R. S. Van de Graaff, who invented the device in 1931. (See *accelerator.*)

vapor suppression A safety system that can be incorporated in the design of structures housing water reactors. In the system, the space surrounding the reactor is vented into pools of water open to the outside air. If surges of hot vapors should be released from the reactor in an accident, their energy (pressure) would be dissipated in the pools of water. Gases not condensed would be scrubbed clean of radioactive particles by the bubbling. Another system uses a suppression pool in a separate pressure vessel that can be vented through a stack. Also called *pressure suppression.* (Compare *pressure vessel.*)

void coefficient A rate of change in the *reactivity* of a water reactor system resulting from a formation of steam bubbles as the power level and temperature increase.

W

waste, radioactive Equipment and materials (from nuclear operations) which are radioactive and for which there is no further use. Wastes are generally classified as high-level (having radioactivity concentrations of hundreds to thousands of curies per gallon or cubic foot), low-level (in the range of 1 microcurie per gallon or cubic foot), or intermediate (between these extremes). (Compare *fission products.*)

water boiler A research reactor whose core consists of a small metal tank filled with uranium fuel in an aqueous solution. Heat is removed by a cooling coil in the core. Not to be confused with *boiling water reactor.*

wet criticality Reactor criticality achieved with the coolant present. (Compare *dry criticality.*)

whole body counter A device used to identify and measure the radiation in the body (body burden) of human beings and animals; it uses heavy shielding to keep out background radiation and ultrasensitive scintillation detectors and electronic equipment. (Compare *scanner;* see *body burden.*)

X

X ray A penetrating form of electromagnetic radiation emitted either when the inner orbital electrons of an excited atom return to their normal state (these are characteristic X rays), or when a metal target is bombarded with high speed electrons (these are bremsstrahlung). X rays are always nonnuclear in origin. (Compare *bremsstrahlung, gamma rays;* see *excited state.*)

Y

yield The total energy released in a nuclear explosion. It is usually expressed in equivalent tons of TNT (the quantity of TNT required to produce a corresponding amount of energy). Low yield is generally considered to be less than 20 kilotons; low intermediate yield from 20 to 200 kilotons; intermediate yield from 200 kilotons to 1 megaton. There is no standardized term to cover yields from 1 megaton upward. (Compare *fission yield;* see *TNT equivalent.*)

Z

Z The symbol for *atomic number.*

zero-power reactor An experimental reactor operated at such low power levels that a coolant is not needed and little radioactivity is produced. (Compare *subcritical assembly.*)

OTHER GLOSSARIES

Popular-level glossaries available include the following:

101 Atomic Terms and What They Mean, Esso Research and Engineering Company, P. O. Box 172, Linden, New Jersey 07036, 1964, 20 pp., free.

Glossary of Atomic Terms, Technical Writers' Section, Public Relations Branch, United Kingdom Atomic Energy Authority, London, 1966, 62 pp., 3 shillings 6 pence ($0.42).

More detailed and more technical definitions and definitions of a more comprehensive list of terms may be found in other books, such as the following:

Atomic Energy Deskbook, John F. Hogerton, Reinhold Publishing Corporation, New York 10022, 1963, 673 pp., $11.00.

Atomic Energy Encyclopedia in the Life Sciences, Charles Wesley Schilling, editor and major contributor, W. B. Saunders Company, Philadelphia, Pennsylvania 19105, 1964, 474 pp., $10.50.

Concise Dictionary of Atomics, Alfred Del Vecchio (Ed.), Philosophical Library, Inc., New York 10016, 1964, 262 pp., $6.00. (Out of print but available through libraries.)

Newnes Concise Encyclopedia of Nuclear Energy, D. E. Barnes et al., advisory editors, John Wiley and Sons, Inc., New York 10016, 1962, 886 pp., $25.00.

Sourcebook on Atomic Energy (third edition), Samuel Glasstone, D. Van Nostrand Company, Inc., Princeton, New Jersey 08540, 1967, 883 pp., $9.25.

Glossary of Terms Frequently Used in Nuclear Physics, compiled by Dr. Robert L. Stearns, American Institute of Physics, New York 10017, 1961, 37 pp., $1.00.

Glossary of Terms Frequently Used in High Energy Physics, compiled by Dr. Allen M. Sachs and Dr. Melvin Schwartz, American Institute of Physics, New York 10017, 1961, 20 pp., $1.00.

APPENDIX

RECOMMENDED UNIT PREFIXES

The following unit prefixes are the ones adopted by the International Committee on Weights and Measures.

Multiples and submultiples	Prefixes	Symbols	Pronunciation
10^{12}	tera	T	tĕr′ȧ
10^{9}	giga*	G	jĭ′gȧ
10^{6}	mega	M	mĕg′ȧ
10^{3}	kilo	k	kĭl′o͟
10^{2}	hecto	h	hĕk′to͟
10	deka	da	dĕk′ȧ
10^{-1}	deci	d	dĕs′ĭ
10^{-2}	centi	c	sĕn′tĭ
10^{-3}	milli	m	mĭl′lĭ
10^{-6}	micro	μ (mu)	mī′kro͟
10^{-9}	nano	n	năn′o͟
10^{-12}	pico†	p	pē′ko͟
10^{-15}	femto	f	fĕm′to͟
10^{-18}	atto	a	ăt′to͟

*Also beva (symbol B, pronounced bĕ′vȧ).
†Also micromicro (symbol $\mu\mu$).

APPENDIX

A NOTE ABOUT NUMERICAL ABBREVIATIONS

Numerical abbreviations used in nuclear science are likely to be composed of two elements: first, an abbreviation of a numerical prefix expressing some multiple or fraction of unity, and second, an abbreviation of a unit which measures some basic property. Examples of both elements are:

PREFIXES

Prefix	Meaning
pico	divide by 1 trillion (10^{-12})
nano	divide by 1 billion (10^{-9})
micro	divide by 1 million (10^{-6})
milli	divide by 1 thousand (10^{-3})
kilo	multiply by 1 thousand (10^{3})
mega	multiply by 1 million (10^{6})
giga	multiply by 1 billion (10^{9})

UNITS
(See preceding pages for definitions)

Unit	Abbreviation	Measured Property
angstrom	Å	length of radiation
barn	b	cross section
curie	c	radioactivity
electron volt	ev	energy
gram	g	mass
meter	m	length
rad	rad	radiation absorbed dose
roentgen	r	radiation dose
rem	rem	radiation dose
second	sec	time
ton	t	nuclear weapon energy in TNT equivalent
watt	w	power

Knowing the two ingredients, it is easy to understand or to employ numerical abbreviations. Examples:

Abbreviation	Full Term	Meaning
mb	millibarn	One thousandth of a barn
μc	microcurie	One millionth of a curie
kt	kiloton	One thousand tons of TNT equivalent

APPENDIX

CONSTANTS

The following values are supplied as useful reference values for students, as recommended by the National Academy of Sciences–National Research Council, and adopted by the National Bureau of Standards:

Constant	Symbol	Definition	Values
Speed of light in vacuum	c	–	2.997925×10^{10} centimeters/sec.
Avogadro number	N	Number of molecules in one gram-molecular weight of a substance.	6.02252×10^{23}
Faraday constant	F	Quantity of electricity to free chemical equivalent weight of a substance (in electrolysis).	9.64870×10^{4} coulombs
Planck constant	h	Energy of quantum of radiation in relation to frequency of source.	6.62556×10^{-27} erg-sec.
Elementary charge	e = F/N	Electric charge on one electron.	4.80298×10^{-10} e.s.u. (electrostatic units).
Electron rest mass	m_e	–	9.1091×10^{-28} gram
Proton rest mass	m_p	–	1.67252×10^{-24} gram

APPENDIX

NUCLIDE DESIGNATION (SUBSCRIPTS AND SUPERSCRIPTS)

In accordance with recommendations of the International Union of Pure and Applied Chemistry, the following designations are used for nuclides:

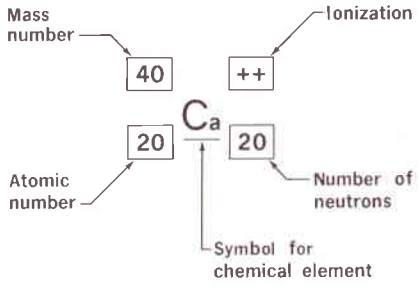
The *MASS NUMBER* of a nuclide is placed as a *superscript* to the left of the symbol for the chemical element of the nuclide, rather than to its right, as formerly; for example, ^{14}N, rather than N^{14} for nitrogen-14.

The *ATOMIC NUMBER* is placed as a left *subscript;* for example, $^{14}_{6}C$ for carbon-14, or $^{235}_{92}U$ for uranium-235.

The state of *IONIZATION* is shown as a *right superscript;* for example, Ca^{++} or SO_4^{--}.

The number of NEUTRONS in the nucleus is shown as a *right subscript;* for example, $^{40}_{20}Ca_{20}$ for the isotope of calcium-40 containing 20 protons (its atomic number) (left subscript), and 20 neutrons (right subscript) in its nucleus.

Excited states are shown either as part of the *left superscript,* or sometimes the *right superscript;* for example: ^{110m}Ag or $^{110}Ag^{m}$ indicates an excited state of a silver-110 nucleus; He* indicates an excited state of a helium atom.



APPENDIX

PERIODIC TABLE OF THE ELEMENTS

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71 La* Series	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103 Act† Series															

*Lanthanide Series	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
†Actinide Series	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	(103) Lr

Transuranium elements are shown in shaded squares. The actinide series of elements as a group occupies a single square in the main figure. The lanthanide series of elements also occupies a single square in the larger chart.

APPENDIX

ALPHABETICAL LIST OF ELEMENTS AND SYMBOLS

Element	Symbol	Atomic number	Atomic weight*
Actinium	Ac	89	227
Aluminum	Al	13	26.98
Americium	Am	95	243
Antimony	Sb	51	121.75
Argon	Ar	18	39.942
Arsenic	As	33	74.91
Astatine	At	85	210
Barium	Ba	56	137.35
Berkelium	Bk	97	249
Beryllium	Be	4	9.013
Bismuth	Bi	83	208.99
Boron	B	5	10.82
Bromine	Br	35	79.913
Cadmium	Cd	48	112.40
Calcium	Ca	20	40.08
Californium	Cf	98	251
Carbon	C	6	12.010
Cerium	Ce	58	140.12
Cesium	Cs	55	132.90
Chlorine	Cl	17	35.455
Chromium	Cr	24	52.01
Cobalt	Co	27	58.94
Copper	Cu	29	63.54
Curium	Cm	96	247
Dysprosium	Dy	66	162.50
Einsteinium	Es	99	254
Erbium	Er	68	167.26
Europium	Eu	63	152.0
Fermium	Fm	100	253
Fluorine	F	9	19.00
Francium	Fr	87	223
Gadolinium	Gd	64	157.25
Gallium	Ga	31	69.72
Germanium	Ge	32	72.60
Gold	Au	79	197.0
Hafnium	Hf	72	178.49
Helium	He	2	4.003
Holmium	Ho	67	164.93
Hydrogen	H	1	1.0079
Indium	In	49	114.81
Iodine	I	53	126.90
Iridium	Ir	77	192.2
Iron	Fe	26	55.85
Krypton	Kr	36	83.80
Lanthanum	La	57	138.91
Lawrencium	Lr	103	257
Lead	Pb	82	207.20
Lithium	Li	3	6.940
Lutetium	Lu	71	174.98
Magnesium	Mg	12	24.32
Manganese	Mn	25	54.94
Mendelevium	Md	101	256
Mercury	Hg	80	200.60
Molybdenum	Mo	42	95.95
Neodymium	Nd	60	144.26
Neon	Ne	10	20.182
Neptunium	Np	93	237
Nickel	Ni	28	58.71
Niobium (Columbium)	Nb	41	92.91
Nitrogen	N	7	14.007
Nobelium	No	102	254
Osmium	Os	76	190.2
Oxygen	O	8	15.999
Palladium	Pd	46	106.4
Phosphorus	P	15	30.973
Platinum	Pt	78	195.08
Plutonium	Pu	94	242
Polonium	Po	84	210
Potassium	K	19	39.098
Praseodymium	Pr	59	140.91
Promethium	Pm	61	147
Protactinium	Pa	91	231
Radium	Ra	88	226
Radon	Rn	86	222
Rhenium	Re	75	186.21
Rhodium	Rh	45	102.90
Rubidium	Rb	37	85.48
Ruthenium	Ru	44	101.1
Samarium	Sm	62	150.34
Scandium	Sc	21	44.96
Selenium	Se	34	78.96
Silicon	Si	14	28.09
Silver	Ag	47	107.875
Sodium	Na	11	22.990
Strontium	Sr	38	87.63
Sulfur	S	16	32.064
Tantalum	Ta	73	180.94
Technetium	Tc	43	99
Tellurium	Te	52	127.60
Terbium	Tb	65	158.92
Thallium	Tl	81	204.38
Thorium	Th	90	232.04
Thulium	Tm	69	168.93
Tin	Sn	50	118.69
Titanium	Ti	22	47.90
Tungsten (Wolfram)	W	74	183.85
Uranium	U	92	238.06
Vanadium	V	23	50.95
Xenon	Xe	54	131.29
Ytterbium	Yb	70	173.03
Yttrium	Y	39	88.92
Zinc	Zn	30	65.38
Zirconium	Zr	40	91.22

*Atomic weight of the most abundant or best known isotope, or (in the case of radioactive isotopes) the isotope with the longest half-life, relative to atomic weight of Carbon-12 = 12.

APPENDIX

THE TRANSURANIUM ELEMENTS

Atomic number	Element	Symbol	Atomic weight*
93	Neptunium	Np	237
94	Plutonium	Pu	242
95	Americium	Am	243
96	Curium	Cm	248
97	Berkelium	Bk	249
98	Californium	Cf	249
99	Einsteinium	Es	254
100	Fermium	Fm	253
101	Mendelevium	Md	256
102	Nobelium	No	254
103	Lawrencium	Lr	257

*Mass number of longest-lived or more available isotope.

APPENDIX

ISOTOPES OF SOME OF THE ELEMENTS*

Element	Isotopes (Mass Numbers)
Hydrogen	1, 2, *3*
Helium	4, 3, *6*
Lithium	7, 6, *8*, *9*
Carbon	12, 13, **14**, *11*, *10*, *15*
Nitrogen	14, 15, *13*, *16*, *17*, *12*
Oxygen	16, 18, 17, *15*, *14*, *19*
Fluorine	19, *18*, *17*, *20*, *21*
Sodium	23, *22*, *24*, *25*, *21*, *20*
Magnesium	24, 26, 25, *28*, *27*, *23*
Aluminum	27, *26*, *29*, *28*, *25*, *24*
Sulfur	32, 34, 33, 36, *35*, *37*, *31*
Chlorine	35, 37, *36*, *39*, *38*, *33*, *34*, *32*
Potassium	39, 41, **40**, *43*, *42*, *44*, *38*, *37*
Calcium	40, 44, 42, 48, 43, 46, *41*, *45*, *47*, *49*, *39*
Iron	56, 54, 57, 58, *55*, *59*, *52*, *53*
Cobalt	59, *60*, *57*, *56*, *58*, *55*, *61*, *62*, *54*
Nickel	58, 60, 62, 61, 64, *59*, *63*, *66*, *57*, *65*, *56*
Copper	63, 65, *67*, *64*, *61*, *60*, *62*, *58*, *66*, *68*
Zinc	64, 66, 68, 67, 70, *65*, *72*, *62*, *71*, *69*, *63*
Bromine	79, 81, *77*, *82*, *76*, *83*, *75*, *74*, *84*, *80*, *78*, *85*, *87*, *88*
Silver	107, 109, *105*, *106*, *111*, *113*, *112*, *103*, *104*, *115*, *108*, *114*, *110*
Tin	120, 118, 116, 119, 117, 124, 122, 112, 114, 115, *123*, *113*, *125*, *121*, *108*, *127*, *126*, *111*, *109*
Iodine	127, *129*, *125*, *126*, *131*, *124*, *133*, *123*, *130*, *135*, *132*, *121*, *134*, *128*, *122*, *137*, *138*, *139*
Barium	138, 137, 136, 135, 134, 130, 132, *133*, *140*, *131*, *128*, *129*, *126*, *141*, *142*, *143*
Platinum	195, 194, 196, 198, 192, **190**, *188*, *191*, *197*, *189*, *187*, *199*
Gold	197, *195*, *196*, *199*, *198*, *194*, *193*, *192*, *191*, *200*, *189*, *201*, *187*, *203*
Mercury	202, 200, 199, 201, 198, 204, 196, *203*, *197*, *195*, *192*, *193*, *191*, *189*, *205*
Lead	208, 206, 207, **204**, *202*, **210**, *203*, *200*, **212**, *201*, *209*, *199*, **211**, **214**, *198*
Bismuth	209, **210**, *207*, *205*, *206*, *204*, *203*, *201*, *202*, **212**, *213*, *200*, *199*, **214**, **215**, *198*, **211**
Radon	**222**, *211*, *210*, *209*, *221*, *212*, *208*, **220**, **219**, *218*, *217*, *216*, *215*
Radium	**226**, **228**, *225*, **223**, **224**, *227*, *213*, *222*, *221*, *220*, *219*
Thorium†	**232**, *223*, *224*, *225*, *226*, **227**, **228**, *229*, **230**, **231**, *233*, **234**
Uranium	**238**, **235**, **234**, *236*, *233*, *232*, *230*, *237*, *231*, *240*, *229*, *239*, *228*, *227*
Neptunium	*237*, *236*, *235*, *234*, *239*, *238*, *240*, *231*, *233*, *241*, *232*
Plutonium	*244*, *242*, *239*, *240*, *238*, *241*, *236*, *237*, *246*, *245*, *234*, *243*, *232*, *235*
Americium†	*243*, *241*, *242*, *240*, *239*, *238*, *245*, *237*, *244*, *246*
Curium†	*248*, *245*, *246*, *243*, *244*, *242*, *247*, *241*, *240*, *238*
Berkelium†	*247*, *249*, *245*, *246*, *248*, *244*, *243*, *250*
Californium†	*251*, *249*, *250*, *252*, *248*, *254*, *253*, *246*, *247*, *245*, *244*
Einsteinium†	*254*, *253*, *245*, *246*, *248*, *249*, *250*, *251*, *252*, *255*, *256*
Fermium†	*257*, *253*, *252*, *255*, *248*, *249*, *250*, *251*, *254*, *256*
Mendelevium	*256*, *255*
Nobelium†	*254*, *255*, *256*
Lawrencium	*257*

*Stable isotopes in ordinary type. Naturally radioactive isotopes in **boldface**. Other radioisotopes in *italics*. Natural isotopes given in order of abundance. All other isotopes given in order of length of half-life.

†Not listed in order of length of half-life.

APPENDIX

RADIOACTIVE DECAY

The Actinium Series

Element	Symbol	Radiation emitted	Half life
Uranium	^{235}U	α	7.13×10^{8} years
Thorium	^{231}Th	β	25.6 hours
Protactinium	^{231}Pa	α	3.43×10^{4} years
Actinium*	^{227}Ac	β (98.8%) and α (1.2%)	21.8 years
Thorium	^{227}Th	α	18.4 days
Francium	^{223}Fr	β	21 minutes
Radium	^{223}Ra	α	11.7 days
Radon	^{219}Rn	α	3.92 seconds
Polonium*	^{215}Po	α (~100%) and β ($\sim 5 \times 10^{-4}$%)	1.83×10^{-3} second
Lead	^{211}Pb	β	36.1 minutes
Astatine	^{215}At	α	$\sim 10^{-4}$ second
Bismuth*	^{211}Bi	α (99.7%) and β (0.3%)	2.16 minutes
Polonium	^{211}Po	α	0.52 second
Thallium	^{207}Tl	β	4.78 minutes
Lead	^{207}Pb	Stable	—

*Undergoes both alpha and beta decay, in definite proportion to decay events, as shown.

The Thorium Series

Element	Symbol	Radiation emitted	Half life
Thorium	^{232}Th	α	1.39×10^{10} years
Radium	^{228}Ra	β	6.7 years
Actinium	^{228}Ac	β	6.13 hours
Thorium	^{228}Th	α	1.91 years
Radium	^{224}Ra	α	3.64 days
Radon	^{220}Rn	α	52 seconds
Polonium	^{216}Po	α	0.16 second
Lead	^{212}Pb	β	10.6 hours
Bismuth*	^{212}Bi	β (66.3%) and α (33.7%)	60.5 minutes
Polonium	^{212}Po	α	3×10^{-7} second
Thallium	^{208}Tl	β	3.1 minutes
Lead	^{208}Pb	Stable	—

*Undergoes both alpha and beta decay, in definite proportion to the decay events, as shown.

The Neptunium Series

Element	Symbol	Radiation emitted	Half life
Plutonium	^{241}Pu	β	13.2 years
Americium	^{241}Am	α	462 years
Neptunium	^{237}Np	α	2.20×10^{6} years
Protactinium	^{233}Pa	β	27.4 days
Uranium	^{233}U	α	1.62×10^{5} years
Thorium	^{229}Th	α	7.34×10^{3} years
Radium	^{225}Ra	β	14.8 days
Actinium	^{225}Ac	α	10.0 days
Francium	^{221}Fr	α	4.8 minutes
Astatine	^{217}At	α	1.8×10^{-2} second
Bismuth*	^{213}Bi	β (98%) and α (2%)	47 minutes
Polonium	^{213}Po	α	4.2×10^{-6} second
Thallium	^{209}Tl	β	2.2 minutes
Lead	^{209}Pb	β	3.32 hours
Bismuth	^{209}Bi	Stable	—

*Undergoes both alpha and beta decay, in definite proportion to decay events, as shown.

The Uranium Series

Element	Symbol	Radiation emitted	Half life
Uranium	^{238}U	α	4.51×10^{9} years
Thorium	^{234}Th	β	24.1 days
Protactinium*	^{234}Pa	β	1.18 minutes
Uranium	^{234}U	α	2.48×10^{5} years
Thorium	^{230}Th	α	8.0×10^{4} years
Radium	^{226}Ra	α	1.62×10^{3} years
Radon	^{222}Rn	α	3.82 days
Polonium†	^{218}Po	α (99.98%) and β (0.02%)	3.05 minutes
Lead	^{214}Pb	β	26.8 minutes
Astatine	^{218}At	α	2 seconds
Bismuth†	^{214}Bi	β (99.96%) and α (0.04%)	19.7 minutes
Polonium	^{214}Po	α	1.6×10^{-4} second
Thallium	^{210}Tl	β	1.32 minutes
Lead	^{210}Pb	β	19.4 years
Bismuth†	^{210}Bi	β (~100%) and α (2×10^{-4}%)	5.0 days
Polonium	^{210}Po	α	138.4 days
Thallium	^{206}Tl	β	4.20 minutes
Lead	^{206}Pb	Stable	—

*Protactinium also undergoes a process of isomeric transition in 0.12% of its decay events. The resulting isomer of ^{234}Pa has a lower energy state. It then undergoes beta decay, with a half-life of 6.7 hours, to form ^{234}U.

†Undergoes both alpha and beta decay, in definite proportion to the decay events, as shown.

APPENDIX

ELECTRONIC ARRANGEMENT OF THE ELEMENTS

	Shells	K	L		M			N				O				P				Q
	Sub-Levels	1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*	4*d*	4*f*	5*s*	5*p*	5*d*	5*f*	6*s*	6*p*	6*d*	6*f*	7*s*
1	Hydrogen	1																		
2	Helium	2																		
3	Lithium	2	1																	
4	Beryllium	2	2																	
5	Boron	2	2	1																
6	Carbon	2	2	2																
7	Nitrogen	2	2	3																
8	Oxygen	2	2	4																
9	Fluorine	2	2	5																
10	Neon	2	2	6																
11	Sodium	2	2	6	1															
12	Magnesium	2	2	6	2															
13	Aluminum	2	2	6	2	1														
14	Silicon	2	2	6	2	2														
15	Phosphorus	2	2	6	2	3														
16	Sulfur	2	2	6	2	4														
17	Chlorine	2	2	6	2	5														
18	Argon	2	2	6	2	6														
19	Potassium	2	2	6	2	6		1												
20	Calcium	2	2	6	2	6		2												
21	Scandium	2	2	6	2	6	1	2												
22	Titanium	2	2	6	2	6	2	2												
23	Vanadium	2	2	6	2	6	3	2												
24	Chromium	2	2	6	2	6	5	1												
25	Manganese	2	2	6	2	6	5	2												
26	Iron	2	2	6	2	6	6	2												
27	Cobalt	2	2	6	2	6	7	2												
28	Nickel	2	2	6	2	6	8	2												
29	Copper	2	2	6	2	6	10	1												
30	Zinc	2	2	6	2	6	10	2												
31	Gallium	2	2	6	2	6	10	2	1											
32	Germanium	2	2	6	2	6	10	2	2											
33	Arsenic	2	2	6	2	6	10	2	3											
34	Selenium	2	2	6	2	6	10	2	4											
35	Bromine	2	2	6	2	6	10	2	5											
36	Krypton	2	2	6	2	6	10	2	6											
37	Rubidium	2	2	6	2	6	10	2	6			1								
38	Strontium	2	2	6	2	6	10	2	6			2								
39	Yttrium	2	2	6	2	6	10	2	6	1		2								
40	Zirconium	2	2	6	2	6	10	2	6	2		2								
41	Niobium	2	2	6	2	6	10	2	6	4		1								
42	Molybdenum	2	2	6	2	6	10	2	6	5		1								
43	Technetium	2	2	6	2	6	10	2	6	6		1								
44	Ruthenium	2	2	6	2	6	10	2	6	7		1								
45	Rhodium	2	2	6	2	6	10	2	6	8		1								
46	Palladium	2	2	6	2	6	10	2	6	10										
47	Silver	2	2	6	2	6	10	2	6	10		1								
48	Cadmium	2	2	6	2	6	10	2	6	10		2								
49	Indium	2	2	6	2	6	10	2	6	10		1	2							
50	Tin	2	2	6	2	6	10	2	6	10		2	2							
51	Antimony	2	2	6	2	6	10	2	6	10		2	3							
52	Tellurium	2	2	6	2	6	10	2	6	10		2	4							

	Shells	K	L		M			N				O				P				Q
	Sub-Levels	1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*	4*d*	4*f*	5*s*	5*p*	5*d*	5*f*	6*s*	6*p*	6*d*	6*f*	7*s*
53	Iodine	2	2	6	2	6	10	2	6	10		2	5							
54	Xenon	2	2	6	2	6	10	2	6	10		2	6							
55	Cesium	2	2	6	2	6	10	2	6	10		2	6			1				
56	Barium	2	2	6	2	6	10	2	6	10		2	6			2				
57	Lanthanum	2	2	6	2	6	10	2	6	10		2	6	1		2				
58	Cerium	2	2	6	2	6	10	2	6	10	2	2	6			2				
59	Praseodymium	2	2	6	2	6	10	2	6	10	3	2	6			2				
60	Neodymium	2	2	6	2	6	10	2	6	10	4	2	6			2				
61	Promethium	2	2	6	2	6	10	2	6	10	5	2	6			2				
62	Samarium	2	2	6	2	6	10	2	6	10	6	2	6			2				
63	Europium	2	2	6	2	6	10	2	6	10	7	2	6			2				
64	Gadolinium	2	2	6	2	6	10	2	6	10	7	2	6	1		2				
65	Terbium	2	2	6	2	6	10	2	6	10	9	2	6			2				
66	Dysprosium	2	2	6	2	6	10	2	6	10	10	2	6			2				
67	Holmium	2	2	6	2	6	10	2	6	10	11	2	6			2				
68	Erbium	2	2	6	2	6	10	2	6	10	12	2	6			2				
69	Thulium	2	2	6	2	6	10	2	6	10	13	2	6			2				
70	Ytterbium	2	2	6	2	6	10	2	6	10	14	2	6			2				
71	Lutetium	2	2	6	2	6	10	2	6	10	14	2	6	1		2				
72	Hafnium	2	2	6	2	6	10	2	6	10	14	2	6	2		2				
73	Tantalum	2	2	6	2	6	10	2	6	10	14	2	6	3		2				
74	Tungsten	2	2	6	2	6	10	2	6	10	14	2	6	4		2				
75	Rhenium	2	2	6	2	6	10	2	6	10	14	2	6	5		2				
76	Osmium	2	2	6	2	6	10	2	6	10	14	2	6	6		2				
77	Iridium	2	2	6	2	6	10	2	6	10	14	2	6	7		2				
78	Platinum	2	2	6	2	6	10	2	6	10	14	2	6	8		2				
79	Gold	2	2	6	2	6	10	2	6	10	14	2	6	10		1				
80	Mercury	2	2	6	2	6	10	2	6	10	14	2	6	10		2				
81	Thallium	2	2	6	2	6	10	2	6	10	14	2	6	10		2	1			
82	Lead	2	2	6	2	6	10	2	6	10	14	2	6	10		2	2			
83	Bismuth	2	2	6	2	6	10	2	6	10	14	2	6	10		2	3			
84	Polonium	2	2	6	2	6	10	2	6	10	14	2	6	10		2	4			
85	Astatine	2	2	6	2	6	10	2	6	10	14	2	6	10		2	5			
86	Radon	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6			
87	Francium	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6			1
88	Radium	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6			2
89	Actinium	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6	1		2
90	Thorium	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6	2		2
91	Protactinium	2	2	6	2	6	10	2	6	10	14	2	6	10	2	2	6	1		2
92	Uranium	2	2	6	2	6	10	2	6	10	14	2	6	10	3	2	6	1		2
93	Neptunium	2	2	6	2	6	10	2	6	10	14	2	6	10	5	2	6			2
94	Plutonium	2	2	6	2	6	10	2	6	10	14	2	6	10	6	2	6			2
95	Americium	2	2	6	2	6	10	2	6	10	14	2	6	10	6	2	6	1		2
96	Curium	2	2	6	2	6	10	2	6	10	14	2	6	10	7	2	6	1		2
97	Berkelium	2	2	6	2	6	10	2	6	10	14	2	6	10	9	2	6			2
98	Californium	2	2	6	2	6	10	2	6	10	14	2	6	10	10	2	6			2
99	Einsteinium	2	2	6	2	6	10	2	6	10	14	2	6	10	11	2	6			2
100	Fermium	2	2	6	2	6	10	2	6	10	14	2	6	10	12	2	6			2
101	Mendelevium	2	2	6	2	6	10	2	6	10	14	2	6	10	13	2	6			2
102	Nobelium	2	2	6	2	6	10	2	6	10	14	2	6	10	14	2	6			2
103	Lawrencium	2	2	6	2	6	10	2	6	10	14	2	6	10	14	2	6	1		2

APPENDIX

PRINCIPAL PRIMARY FISSION PRODUCTS

Isotope	Symbol	Half Life
Strontium	^{89}Sr	53 days
Strontium	^{90}Sr	28 years
Yttrium	^{90}Y	64.2 hours
Yttrium	^{91}Y	57 days
Zirconium	^{95}Zr	65 days
Niobium	^{95}Nb	35 days
Molybdenum	^{99}Mo	68.3 hours
Ruthenium	^{103}Ru	39.8 days
Ruthenium	^{106}Ru	1 year
Rhodium	^{103m}Rh	57 minutes
Rhodium	^{106}Rh	30 seconds
Tellurium	^{132}Te	77.7 hours
Iodine	^{131}I	8.1 days
Iodine	^{132}I	2.4 hours
Xenon	^{133}Xe	5.27 days
Cesium	^{137}Cs	30 years
Barium	^{137}Ba	2.6 minutes
Barium	^{140}Ba	12.8 days
Lanthanum	^{140}La	40 hours
Cerium	^{141}Ce	32.5 days
Cerium	^{144}Ce	290 days
Praseodymium	^{143}Pr	13.7 days
Praseodymium	^{144}Pr	17.5 minutes
Neodymium	^{147}Nd	11 days
Promethium	^{147}Pm	2.6 years
Promethium	^{149}Pm	54 hours

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